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WARS AND THEIR EFFECT ON AGRICULTURE WITH PARTICULAR REFERENCE TO CANADIAN EXPERIENCES[1]

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Any attempt to appraise the probable effect of the present war on the agriculture of our various countries will, to say the least, be difficult at this time. Nevertheless it is a question of very general interest and one to which the attention of this Committee has been directed.

In dealing with the matter one naturally thinks of past experiences, particularly those of the last war and post-war period. And while it would be dangerous to assume that all of the economic consequences of that period will be duplicated in this, yet it may be profitable to review what happened. From such a review certain factors may stand out in more or less clear relief, and some of the possible effects of the present situation may suggest themselves.

PRICE MOVEMENTS 1914–20

Between 1914 and 1920 the all-commodity index of wholesale prices in Canada increased from 102 to 243 in terms of the 1913 average. The index of the wholesale prices of farm products went from 111 to 259. Stimulated by such a material increase in prices, and encouraged by national efforts to increase the output of war necessities, the production of food products naturally came in for special consideration.

It may be well at the outset to direct attention to the fact that the most pronounced increases in price came during the latter years of the war and in the immediate post-war years. Thus the all-commodity index of wholesale prices in 1915 was only 7 points higher than in 1914, while the index of farm products, where an early upward movement was followed by a recession, averaged only 14 points higher. In contrast the wholesale index went up 47 points from 1916 to 1917 and from 10 to 30 points in each of the succeeding three years. The farm price index meanwhile jumped 64 points in 1917, remained almost at the same point in 1918 and then went ahead again at a renewed pace until 1920.

It is perhaps significant to note that apart from wheat very little effort was directed toward price control during the first World War. A Food Board was created in 1917 but its activities were directed mainly toward increased production and conservation through patriotic appeals.

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An agency was created in 1917 which established a fixed price for wheat that year and in 1918; then in 1919 the Canadian Wheat Board handled the crop for farmers on what amounted to a co-operative plan, with government direction. The Food Board also issued licences and endeavoured to regulate the trade in certain important products. Apart from these efforts, however, the production economy was influenced but slightly by regulation. The increases in output that occurred were directly attributable to three things: (1) natural increase associated with pioneer settlement, (2) increased prices resulting from war-time inflation, (3) patriotic efforts directed toward greater production.

We should perhaps pause at this point to emphasize that not all of the increase in production during the war and post-war period was attributable to the war itself. The Introductory Note to the discussion on this subject prepared by the Geneva Office for this meeting has taken note of this situation but it needs further emphasis. In Western Canada where a great increase in agricultural production was recorded, the period of pioneer settlement was still in progress when war broke out. A moderate movement of home seekers during the "eighties and nineties" was succeeded by a rapid increase of settlement with the turn of the century and continued up to and through the war period. Thus the area seeded to wheat, which totalled 8.8 million acres in 1910, was increased to 11 million in 1913. The acreage of oats in 1910 was 8.6 and in 1913, 10.4. Similar increases were in progress in other fields of agricultural production. In brief, it was to be expected that millions of acres of virgin land settled during the decade before the war would be brought under cultivation in succeeding years.

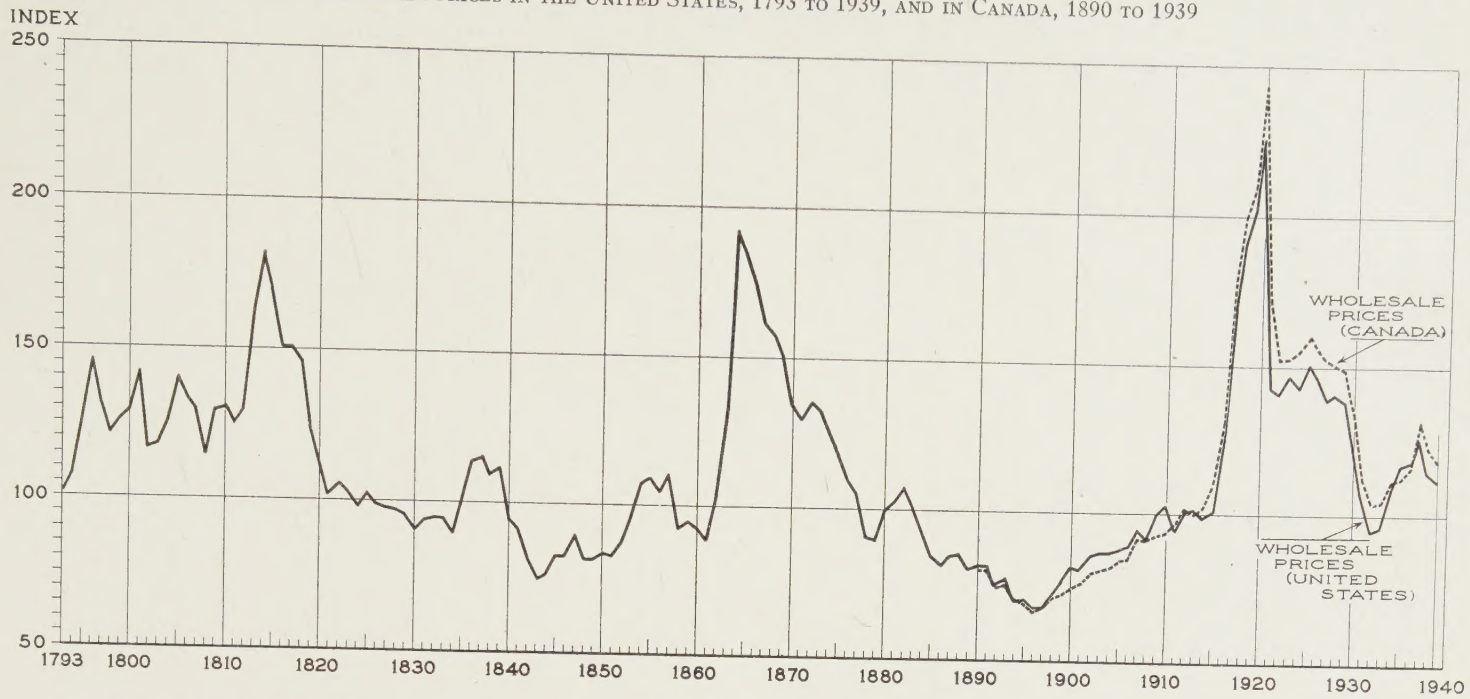
A gradual improvement in the prices of farm products, which carried the index from 67 to 102 between 1896 and 1914, was doubtless an important factor contributing to westward expansion. In any event the outbreak of war in 1914, despite some evidence of economic uncertainty, found agriculture on an expanding plane. In succeeding years war-time prices and patriotic appeals for increased production provided further incentives for even greater activity.

PRODUCTION RESPONSE

Stimulated by the forces already mentioned, production of food products was greatly increased during the war and post-war period. But whatever the net effect of the war on total production, it is significant that individual products were affected in different ways. Thus, for instance, the production of cheese, already on the decline, continued its downward movement. The production of concentrated milk products was only slightly affected. Butter production continued its moderate upward trend and exports were increased.

It is difficult to distinguish between the effect of the war and that of normal cyclical movements on livestock production but it is noted that the numbers of cattle, sheep and swine all increased materially during the war. The numbers of cattle on farms in Canada increased from 6 million to more than 10 million during the war and exports more than doubled. With the cessation of hostilities production fell off materially and has never since reached war-time levels. There was a 20 per cent increase in

WHOLESALE PRICES IN THE UNITED STATES, 1793 TO 1939, AND IN CANADA, 1890 TO 1939



High prices during the Napoleonic Wars, the United States Civil War, and the World War were succeeded by periods of from 20 to 30 years of declining prices. These were difficult times for farmers.

the number of pigs on farms between 1914 and 1918 and bacon exports to the United Kingdom, stimulated by imports of bacon from the United States, jumped from 27 million pounds in 1913 to 242 million pounds in 1919. Exports of bacon declined drastically after 1919 and very nearly disappeared by 1930. Since that time there has been a return to something like the last war period. The Canadian surplus for export will again be well over 200 million pounds this coming year. This is a significant situation. Sheep production increased materially during the last war and exports even more significantly, though the total was not a large item in the war-time economy.

The production of potatoes, tobacco, honey and maple products was increased but the most important development and the one affecting both Canadian and world economy most significantly occurred in the case of wheat. Here the acreage, continuing the trend already noted, went from 11 million in 1913 to 19 million in 1919, and, following a decline in 1920, reached a peak of 23 million acres in 1921. Thereafter the acreage dropped off and did not again attain its war-time level until 1928. During the war period acreage also increased in certain other major exporting countries and international trade increased from a pre-war level of around 600 million bushels (excluding Russia) to a post-war level nearly fifty per cent in excess of this amount. The subsequent restoration of something like pre-war acreages in central and western Europe, and the occurrence of favourable yields and large crops in exporting countries, led to large surpluses and marketing problems of a serious nature.

WAR-TIME PROSPERITY

The increase of prices during the period from 1914 to 1920 brought prosperity to many branches of Canadian agriculture. A somewhat slower upward movement of the general price level added to the farmer's advantage. As a result, purchasing power was relatively favourable. Much of the increased revenue went into additional farm equipment and enlarged farms. The trend toward mechanization and the fact that many farmers at the outbreak of war had not yet emerged from the settlement stage, and thus would normally require to enlarge their holdings, combined to bring about substantial purchases of land. Under the stimulus of rising prices and increased demand land values rose very appreciably.

Many farmers incurred heavy indebtedness during this period to acquire this additional land and equipment; and to make matters worse, the wheat crops of 1918 and 1919 were substantially below normal. Wages of farm labour during the period increased from an average of $155 per year in 1914 to $543 in 1920.

THE POST-WAR DEPRESSION PERIOD

Then came the post-war depression. The all-commodity index of wholesale prices declined from 243 in 1920 to 152 in 1922, while the index of farm prices dropped from 259 to 128 in 1923. The greater decline in the farm price index reduced the purchasing power of farmers very appreciably and made the payment of fixed charges on indebtedness incurred at higher price levels particularly burdensome. A serious dislocation of production occurred—the output of some products was reduced, of others,

increased. Some regions were affected more than others. Wages were reduced and land values declined. Legislation providing for the adjustment of indebtedness was introduced in Saskatchewan.

THE RECOVERY PERIOD AND SECOND POST-WAR DEPRESSION

During the years from 1924 to 1929 a marked recovery took place, and relative prosperity again reigned in Canadian agriculture, only to be followed by a still more serious readjustment from 1930 to 1933. During this latter period prices actually declined to a level substantially below the scale of 1913. Needless to say agriculture was drastically affected. Actually the situation in Canada was made much more acute by reason of a succession of exceedingly poor crops in the great wheat producing areas. During this period, largely due to drought, though not entirely, many thousands of farmers required assistance in one form or another. Much legislation of a remedial nature was passed by legislative bodies. One of the measures adopted provided financial assistance to enable farmers to employ necessary help. Another made voluntary or compulsory adjustment of debts possible. Actually, however, the amount of adjustment agreed to by creditors without reference to legislation greatly exceeded the volume resulting from references to legislative authority.

Looking back over the period since the last war, it is evident that the war's effects on agriculture have been quite pronounced. Of the 19 years that have elapsed since the end of the post-war inflation in 1920, no less than 13 have been unfavourable to farmers if the prices of his products relative to other products is used as a criterion. In 5 of these years the difference, indicated by comparative indexes, amounted to 20 points or more. In all but 3 of the years the discrepancy was more than 10 points. In only 5 of the 19 years did farmers enjoy an advantage and in none of these did the advantage amount to more than 10 points.

It cannot be said that the war alone was responsible for this unfavourable relationship. Many other conditions have contributed to lack of stability and to adverse economic conditions. Many, however, will agree that the undue expansion associated with the war and post-war period, the heavy commitments for land and machinery, and the establishment of standards of expenditure difficult to maintain on a normal standard of income, contributed to the unfavourable conditions experienced by farmers during the period under review.

It should perhaps be observed that similar developments occurred as a result of other important wars, notably the Napoleonic War in Europe and the American Civil War. In each case a prolonged period of agricultural distress, lasting from 20 to 30 years, followed.

Although measures to regulate production have been adopted by many countries during recent years, Canadian farmers have not considered such activities desirable. Assistance in the marketing of farm products has been provided in one form or another by both Provincial and Dominion Governments but only a minimum of effort has been devoted to the matter of regulation and control. On the contrary, major interest has centred in the promotion of agricultural commerce in the belief that this is the most effective means of improving economic conditions; to this end many trade agreements with other countries have been completed.

THE PERIOD PRECEDING THE PRESENT WAR

Although the output of Canadian farms responded to changes in price during each of the post-war periods of depression and prosperity, the position of Canadian agriculture in September of this year, as far as production is concerned, approached or exceeded the level of the last war in the case of most products. The population of Canada has increased in the meantime, it is true, but in the output of most basic commodities required for the feeding of both fighting forces and civilian population Canada has surpluses for export that compare favourably with, or exceed, the amounts available at the peak of production during the period 1914 to 1918. Actually our surplus of wheat is very large. Our production of meats, dairy products, poultry products and fruits is of such proportions as to permit of heavy exports. This factor and our relative proximity to Europe may have a significant bearing on the outcome of the war and on the economic position of Canadian farmers.

THE PRESENT SITUATION

For several years the preparations for war have disturbed the economy of nations, and on September 1, 1939, war again became a reality. Our first question may well be "What will be the effect?" The International Labour Office has, very wisely it would seem, directed the attention of this Committee to this question. It is probably not an overstatement to say that no one expects a final answer at this time.

A review of what happened during the last war and succeeding years, such as has been presented by other speakers, and has been attempted in this discussion, may be of value in this connection but it would be a mistake to assume that the experiences of the last war period will be duplicated in every particular during this one.

In the first place, the supply situation is materially different from that existing in 1914. There are to-day large surpluses of many basic products. Canada has, as already stated, a large surplus of wheat. Other countries, too, have wheat, sugar, cotton, coffee and other products. Stocks of some of these products are reported as having been accumulated by the belligerent countries.

In the second place, a material change has occurred in the economy of nations. Whereas the last war found most countries operating under a competitive system with a minimum of regulation and restriction, the present conflict opens with most countries engaged in some measure of control. Further efforts will undoubtedly be made to regulate production, prices and trade in many countries.

CANADA'S POSITION

Canada, the only belligerent represented at this meeting, may experience effects that will differ from those experienced by other nations here represented. The effect will, of course, depend upon the net trading position of the respective countries. It may depend, too, upon the existence or non-existence of bonds of association. The nature of products produced may be a factor to be considered. The financial standing of countries must also be considered. The shift from a debtor to a creditor position experienced by the United States during the last war may conceivably be the lot of certain nations in this war if it lasts for some time.

The outbreak of hostilities in September, as far as Canada is concerned, was marked by an almost immediate rise in prices of food products. Butter went from 21 to 27 cents a pound, cheese from 10.6 to 14 cents, eggs from 27 to 40 cents per dozen, potatoes from 60 cents to $1.10 per cwt., butcher steers from $6.50 to $7.50 per cwt., bacon hogs from $7.60 to $9.00 per cwt., wool from 12 cents to 18 cents per pound and wheat from a low of 51 cents on August 15 to 82 cents on September 7. Wheat has since declined to around 70 cents and the prices of several other products have also fallen off. It should perhaps be noted, however, that even with such increases the prices of farm products are not unreasonable.

It has already been noted that the outbreak of war in 1914 brought similar increases and subsequent declines of a similar nature, before a sustained rise took place in 1916.

The recollection of what happened to sugar prices in the last war was responsible for a "run" on sugar supplies in September, and stocks that would have proven adequate for normal demands turned out to be quite insufficient to meet the increased purchases attributable to "hoarding". Steps were taken by merchants to limit sales and by both refineries and the government to increase supplies. This impulse to buy sugar was a psychological development resulting from earlier war experiences. There was no other basis for apprehension—supplies were, and are, adequate for all needs.

War conditions plus a large crop in England have affected the sale of Canadian apples to England. The Canadian Government has taken steps to assist with the conversion of larger than normal quantities of the fruit into processed forms and is also assisting the industry in other ways. Certain other products have been affected by changed demand and supply conditions but appropriate steps have been taken to deal with the situation in each case.

To meet these and many other problems that have already arisen or will arise, Canada has taken definite steps to place her activities on a war-time basis. Among these are the creation of two Boards of special interest to farmers, one to deal with the production and marketing of food products, the other to deal with prices. Steps have already been taken by these Boards to assist agriculture.

It is not possible at this stage to forecast the exact nature of Canada's war efforts in the months or years to come. Certain it is that every effort will be made by the government and the people to carry the war through to a successful conclusion. Farmers will do their share in this effort. It is desired, however, to avoid unbalanced production and over-emphasis on particular products as far as possible. The probable after-effects are likely to receive more consideration in this war than during the last one.

To date, Britain has indicated a greater interest in supplies of cheese, bacon, and wheat from Canada. Eggs have also been the subject of some enquiries and beef may be required in larger volume. No campaign has been developed, however, to increase production, but the Minister of Agriculture, Hon. J. G. Gardiner, in a very recent address, made the statement that "no mistake will be made, whatever the future has in store, if the production of cheese, bacon and eggs is increased." In making this state-

ment, he has kept in mind the requirements of a sound agricultural development in a peace-time agricultural economy for Canada.

CONCLUSIONS

While, as stated earlier in this discussion, it may be difficult and perhaps dangerous to attempt to forecast the final effect of this war on agriculture, it may, on the basis of past experience, be possible to suggest in general terms certain results that are likely to follow. In the first place differences in the present supply situation and in the degree of governmental control compared with 1914, suggest a less rapid upward movement of prices than might otherwise be expected. If, however, the conflict lasts for any considerable time and millions of men are withdrawn from normally productive occupations, including farming, supplies will decrease, demand increase and prices rise. Such a development might be expected to affect the surplus-food producing countries of the Americas in general and Canada in particular.

An increase in prices—which would probably be greatest in the case of raw materials, including farm products—would reduce the disparity at present unfavourable to agriculture in most countries. An improvement in economic and social conditions would result, at least for the time being. Producers of some products would benefit more than others—some might even fail to derive any benefit at all. However, despite the probability that some temporary advantage would accrue to farmers as a group from a development such as that envisaged, the experiences of the past suggest that the long-time effect of war is likely to be a lowering of the standard of living and of the general welfare of those associated with agriculture.

PROTEIN REQUIREMENTS OF WEANLING PIGS[1]

THE INTER-RELATIONS BETWEEN THE PROTEIN LEVEL OF THE DIET, THE AMOUNTS OF FEED CONSUMED DAILY, AND THE RATE OF GAIN OF THE PIGS

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The problem of providing in man-made rations the optimum amounts of the proper kinds of protein has been ever present since the advent of scientific feeding of pigs. So many factors are now known to affect the question that hope of expressing the protein requirement in any relatively simple "feeding standard" has dwindled almost to the vanishing point.

Not the least of the complicating factors is the fact that no accurate statement of the minimum protein need can be hoped for at present from observation of comparative feeding trials. The protein, or rather amino acid complex, in a given ration is largely unknown, and hence minimum or optimum dietary levels on one ration may not hold for another. Even methods based on minimum endogenous urinary nitrogen excretions do not clarify the question of quality of dietary protein needed.

In the meantime, however, pigs must be fed. And it is with this fact in mind that this paper is presented, its limitations as a contribution to the fundamental problem of minimum protein requirement of weanling pigs being fully appreciated.

Turning first to the problem of quality of protein, it is conceded that for growing animals, other than herbivora, dietary protein must provide certain amino acids which the body is unable to synthesize or unable to synthesize rapidly enough to permit rates of growth otherwise possible. However, aside from data presented by Rose (6) for rats, no workable knowledge as to the proportions or amounts of these essential acids needed in the ration is thus far at hand.

Tests at Macdonald College, in which results were measured by rate of growth of pigs and by feed efficiency, have shown the superiority of non-oily fishmeal over linseed oilmeal or dry rendered tankage as supplements to a basal ration of corn and minerals. This we interpret to confirm the general belief that proteins of animal origin are usually superior nutritionally to those from vegetable sources. The superiority of fishmeal over tankage which is rather consistently shown in Eastern Canadian trials may be a reflection of heat damage incidental to the removal of fat in the manufacture of the latter product.

Other studies at Macdonald College lead us to believe that the proteins of animal origin need not constitute over 25% of the mixed protein supplement. How far the proportion of animal protein may be reduced will obviously depend in part on its specific nature. Until such time as more complete knowledge of the composition of these products is available, the

[1] Paper read before the American Society of Animal Production, Chicago, December, 1939. Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Journal Series No. 134.

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guide offered by Plimmer (5) for human dietary standards that one-half the protein should be of animal origin, may prove equally useful for weanling pig rations.

Returning to the question of amounts of dietary protein advisable or needed in the weanling pig ration, attention is directed in this paper to a problem which has arisen in most of our tests and which, while it obviously must have a direct bearing on the matter of optimum dietary protein level, appears to have been only infrequently mentioned in the literature; namely the inter-relations of dietary protein level, quantity of feed eaten, and rate of gain by the pigs. Mitchell and Hamilton (4) hint at this problem when in referring to their estimate of pig requirements they note that, "In applying these estimates it should be kept in mind that they are based upon a moderate rate of growth . . . For more rapid rates the estimates should be increased . . ."

If it is true, as found by McMeekan (3) that rate of gain of the pig, especially during the early stages of growth, is of significance in the type of carcass ultimately produced, then an idea of how much the dietary protein and/or energy must be changed from any given standard to be compatible with different rates of gain is at once of practical importance.

It of course may be argued that the feed intake of pigs fed *ad libitum* (or hand full fed) is neither predictable nor controllable. There are, however, ample records to prove that average daily gains of 1.35 pounds by pigs between the time of weaning and a weight of 100 pounds is by no means impossible. Further, each pound of gain by such pigs on efficient rations should not require more than 3 pounds of feed, or an average daily intake of about 4 pounds air dry feed. Thus if a given ration is not voluntarily eaten in amounts comparable to these figures, it may well be that the diet is nutritionally incomplete or unbalanced (2, 1).

Regardless of the factors which regulate voluntary food intake, it is evident that live weight gains are related both to amounts of total feed eaten and to protein intake. These relationships may be quantitatively determined, given data suitable for the solution of the equation:

$$y = k + b_1(x_1) + b_2(x_2)$$

where y is the average daily gain of the pig, x_1 and x_2 the daily protein and daily feed intakes respectively, b_1 and b_2 the partial regressions of gain on protein and on feed respectively and k, a constant expressing the amount of gain not accounted for by the 2 independent variables.

Such data were available at Macdonald College from some 10 different feeding trials involving 58 feeding groups. The pigs in all trials were individually penned. Feed intake records and gains were individually recorded, and included only periods between weaning time and a weight of about 100 pounds. The basal rations were of mixed cereal grains, largely barley; and the protein was supplied by combinations of which those already described were typical. Excepting for pigs of 5 lots in one trial that received restricted rations, feed was allowed to the limit of appetite.

Statistical methods of analysis of variance and covariance and of partial regression were used in the reduction of the data. Average values for gains, feed intake and protein level of each feeding group were treated as single observations. The total variance for the 58 lots was partitioned to isolate and remove that due to the 10 trials. The correlations and

regressions were then calculated from the "between lot within trial" residual, thus giving 48 degrees of freedom with which to test their significance.

The means and the between group variability are shown in Table 1.

TABLE 1.—AVERAGE DAILY GAINS, DAILY FEED, DAILY PROTEIN AND PROTEIN PERCENTAGE IN THE RATIONS

Item	Mean	Range	σ	C.V.
Daily gain in weight	1.08 lb..	.42 – 1.46	.1747	16.2
Daily feed intake	3.25 lb.	1.64 – 4.83	.3914	12.0
Daily protein intake	.65 lb.	.24 – 1.01	.1025	15.8
Per cent protein of rations	20.1 %	14.8 –23.8	2.0006	10.0

The simple correlations between these 4 variables are given in Table 2.

TABLE 2.—SIMPLE CORRELATIONS BETWEEN GAINS, FEED INTAKE AND PROTEIN CONSUMPTION, AND PARTIAL CORRELATION BETWEEN GAIN AND PROTEIN INTAKE WITH FEED CONSUMPTION CONSTANT

	Daily feed eaten	Protein eaten daily, lb.	Protein in ration, %
Daily gain in weight	.8662	.8471	.3111
Daily feed eaten	—	.8115	.0701
Lb. protein eaten daily	—	—	.6149
Daily gain in weight	.4938	Constant	—

r needed for P 0.01 = 0.354

The partial correlation between gain and daily protein intake with daily feed constant was found to be 0.4938, which indicates that there is a tendency for pigs consuming the greater quantities of protein, but eating the same amount of feed, to gain more than those eating less protein per day.

The partial regressions (b) and the standard regressions (β) are given in Tables 3 and 4.

TABLE 3.—STANDARD AND PARTIAL REGRESSIONS OF DAILY PROTEIN AND DAILY FEED ON DAILY GAIN

	Beta	Relative wt. of B's	b
Daily protein	.4222	44.6%	.7196
Daily Feed	.5236	55.4%	.2337

R^2 = 0.8112 and R = 0.9007 R needed for P 0.01 = 0.410

It is of interest to note that daily feed intake and the protein intake account for about 81% of the variations in daily gains of the pigs; (R^2 = 0.81). It is also significant that, within the range of protein intake of these tests, level of total feed intake is of greater weight in determining changes in rate of gain than is protein intake whether the latter is expressed

as pounds eaten daily (Table 3) or as percentage protein of the ration (Table 4). The partial regression coefficients of Table 3 indicate that:

At the same level of protein intake, an increase of 0.23 pounds gain may be expected with 1 pound increase in daily feed.

At the same level of feed intake, a similar increase in gain (0.23 pounds) may be expected with increases of 0.31 pounds protein intake. Table 4 is interpreted in a similar manner.

TABLE 4.—STANDARD AND PARTIAL REGRESSIONS OF PER CENT PROTEIN OF RATION AND DAILY FEED ON DAILY GAIN

	Beta	Relative wt. of B's	b
Per cent protein	.2516	22.9%	.0220
Daily feed	.8486	77.1%	.3788

$R^2 = 0.8133$ and $R = 0.9018$ R needed for P 0.01 $= 0.410$

With the values of Tables 1 and 3 (or 4) the regression equations can be written:

$$1.08 = -0.15 + 0.7196(0.65) + 0.2337(3.25)$$

or using x_1 as percentage protein of the ration instead of pounds of protein eaten daily,

$$1.08 = -0.59 + 0.0220(20.1) + 0.3788(3.25)$$

These equations may be used to predict the daily gains over a range of protein and feed intakes. Values of interest at this time have been calculated and are given in Tables 5 and 6.

TABLE 5.—AVERAGE DAILY GAINS (IN POUNDS) TO BE EXPECTED OF WEANLING PIGS* ACCORDING TO DAILY FEED EATEN AND THE POUNDS PROTEIN IT CONTAINED

Pounds daily protein eaten	Average daily feed eaten		
	3.00 pounds	3.50 pounds	4.00 pounds
.30	.77	.89	1.01
.50	.91	1.03	1.15
.70	1.06	1.18	1.30
.90	1.20	1.32	1.44

* Pigs from weaning to a live weight of 100 pounds.

TABLE 6.—AVERAGE DAILY GAINS (IN POUNDS) TO BE EXPECTED OF WEANLING PIGS* ACCORDING TO DAILY FEED EATEN AND THE PER CENT PROTEIN IT CONTAINED

Per cent protein in ration	Average daily feed eaten		
	3.00 pounds	3.50 pounds	4.00 pounds
15	.87	1.06	1.25
17	.92	1.11	1.30
19	.96	1.15	1.34
21	1.01	1.19	1.38
23	1.05	1.24	1.43

* Pigs from weaning to a live weight of 100 pounds.

DISCUSSION AND CONCLUSIONS

As already pointed out, the observed values for the daily protein intake, or for the percentage protein of the rations cannot be taken as accurately indicating the optimum protein levels for weanling pigs when measured in terms of gain in live weight of the pigs. For diets in which the source of the protein fraction is similar to that of these tests, these data point to the necessity of considering the level of food intake in any standard for protein requirements.

Within a given level of daily feed consumption, increasing the percentage protein of the ration may be expected to result in increased gains. But also increased gain will result from increased food intake at a given level of protein intake. Thus protein requirements determined by any method are inseparably linked with average daily food consumption and due allowances for various levels of total food intake must be made in any workable feeding standard.

For example, Morrison gives the requirements of a 75-pound pig as 3.4 pounds dry matter and 0.31 pounds digestible protein. These are approximately equivalent to 3.75 pounds of feed and 0.40 pounds total crude protein. Intakes of this level should result in a daily gain of about 1 pound. If less feed is eaten, however, but with the same daily protein intake, less rapid gains must be expected, unless the percentage protein of the diet is raised enough to result actually in a greater consumption of protein per day. This is illustrated in Table 6, when it is seen, for example, that to obtain the same daily gain on a diet eaten at 3.50 pounds per day as would be obtained were 4.00 pounds of feed eaten requires that the protein percentage of the ration be raised by some 8 units.

One should not exclude the possibility that incidental to the increase of the protein intake, there is an increase in some other dietary factor which is fundamentally the cause of increased gain.

Another point of significance emerges from Table 5. Within any given ration intake level, the efficiency of the dietary protein decreases with increasing protein intake. This decrease in biological value with higher intakes is of course well known. Its extent, however, is seldom appreciated.

If these results are substantiated it would seem that some uncertainty will necessarily be attached to any practical feeding standard in which a fixed biological value of the protein is assumed in arriving at the requirement.

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DIGESTIBILITY STUDIES WITH RUMINANTS*

VII. PLANE OF NUTRITION AND DIGESTIBILITY OF A HAY-OIL CAKE RATION

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In a previous paper (2) the effect of the plane of nutrition upon the digestibility of a hay-barley ration was studied. In that case, as the plane of nutrition increased, the digestibility of the dry matter, organic matter, ether extract, and nitrogen-free extract, decreased. The magnitude of this decrease was to the order of 1 to 2%. Only in the case of nitrogen-free extract, however, was the decrease statistically significant. In the case of the nitrogen there was a marked decrease of digestibility of some 6% which was statistically significant. The digestibility of the crude fibre was not affected by the level of feeding. The present paper describes a similar study with a protein concentrate, namely, oil cake meal.

The experimental animals consisted of 5 grade Shorthorn steers, designated D, E, F, G, and H. The first 4 were $2\frac{1}{2}$ years old and the other 3 years old. The average weights were, respectively, 452, 465, 412, 499, and 509 kilogrammes. The rations consisted of equal parts of hay and oil cake meal fed at levels of 2, 4, 6, and 8 kilogrammes and *ad libitum* per animal per day. The levels have been numbered I to V, inclusive.

The *ad libitum* feeding trials were conducted as follows: 9 kilogrammes of the mixed ration were fed during the preliminary period and also during the last 4 days of the collection period. During the first 8 days of the collection period, the animals were given the maximum quantity they would eat each day. In the case of one animal the average daily quantity consumed throughout the trial for *ad libitum* feeding was slightly over $8\frac{1}{2}$ kilogrammes; for 2 others it was slightly over 9 kilogrammes; and for the remaining 2, the average daily consumption was slightly over 10 kilogrammes.

The experiment was set up in the form of a 5 × 5 randomized Latin square consisting of 5 periods as given in Table 1. The periods consisted of a 12-day preliminary period and a 12-day collection period. Adjustments were made in each of the last 4 periods in the quantity of hay fed so as to maintain a constant ratio between the dry matter contents of the hay and oil cake meal throughout the experiment. For Levels I to IV, inclusive, these changes were made on the first day of the collection period. In the case of the *ad libitum* feeding trials, they were made on the eighth day of the collection period. The changes are given in Table 2.

The hay was part of the lot described in a previous paper (3) to which reference should be made for the complete botanical analysis. Essentially

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TABLE 1.—DAILY RATIONS IN KILOGRAMMES

(Ration consists of equal parts by weight of hay and oil cake meal)

Period	Ration				
	Animal D	Animal E	Animal F	Animal G	Animal H
1	2	4	6	*ad lib.**	8
2	6	2	8	4	*ad lib.**
3	8	*ad lib.**	2	6	4
4	*ad lib.**	6	4	8	2
5	4	8	*ad lib.**	2	6

* Basal level of 9 kilogrammes changed according to animal's capacity.

TABLE 2.—AMOUNTS OF HAY REMOVED FROM RATIONS OF EACH PERIOD OF 12 DAYS TO MAINTAIN A CONSTANT DRY MATTER RATIO

(Weight in grams)

Period	Hay removals				
	Animal D	Animal E	Animal F	Animal G	Animal H
2	76	25	102	51	131
3	389	450	97	292	195
4	657	378	252	504	126
5	432	863	1025	216	647

it consisted of approximately 80% timothy, 12% alfalfa and 8% miscellaneous. As explained in that paper, the composition and digestibility of the hay changed suddenly during the season. In this present experiment the change took place in Period 5. To calculate the coefficients of digestibility of oil cake, therefore, it was necessary to use one set of values of the hay for Periods 1 to 4, inclusive, and another set for Period 5. These values were taken from a previous paper (3). In this present investigation, however, the conclusions concerning the effect of the plane of nutrition upon digestibility were based upon the observed values of the total rations and not on the calculated values of oil cake.

The oil cake meal was "Screwpress Linseed Oil Cake Meal" manufactured in Canada.

The experimental data are given in Tables 6 and 7 in the Appendix. A summary of the coefficients of digestibility of the total rations is given in Table 3, with an analysis of variance in Table 4.

It will be observed that the coefficients of digestibility of the dry matter, organic matter, and nitrogen-free extract, as well as the total digestible nutrients in percentage of dry matter, were practically identical for Levels I and II. From Level II to Level V there was a progressive decrease in digestibility amounting to nearly 4 absolute per cent. The coefficients of digestibility of the crude fibre showed a marked progressive drop of approximately 9 absolute per cent from the lowest to the highest level of feeding. All these changes were statistically significant.[1]

[1] In this paper, significance is determined at 5% points.

TABLE 3.—COEFFICIENTS OF DIGESTIBILITY OF TOTAL RATION ARRANGED BY PERIODS AND PLANE

(Coefficients in per cent, animal numbers in brackets)

Nutrient	Period	Plane I	Plane II	Plane III	Plane IV	Plane V	Means
Dry Matter	1	62.6 (D)	60.2 (E)	58.8 (F)	60.7 (H)	57.2 (G)	59.9
	2	59.5 (E)	60.1 (G)	59.7 (D)	56.8 (F)	56.6 (H)	58.5
	4	60.8 (F)	61.4 (H)	61.0 (G)	59.5 (D)	58.0 (E)	60.1
	4	63.1 (H)	61.3 (F)	60.6 (E)	60.2 (G)	58.5 (D)	60.7
	5	61.5 (G)	64.5 (D)	62.9 (H)	58.9 (E)	59.3 (F)	61.4
	Means	61.5	61.5	60.6	59.2	57.9	60.15
Organic Matter	1	64.6 (D)	62.2 (E)	60.6 (F)	62.7 (H)	59.1 (G)	61.8
	2	61.8 (E)	62.2 (G)	61.6 (D)	58.8 (F)	58.5 (H)	60.6
	3	62.7 (F)	63.7 (H)	63.0 (G)	61.6 (D)	59.9 (E)	62.2
	4	65.4 (H)	63.4 (F)	62.6 (E)	62.1 (G)	60.7 (D)	62.8
	5	64.4 (G)	66.9 (D)	65.4 (H)	61.0 (E)	61.1 (F)	63.8
	Means	63.8	63.7	62.6	61.2	59.9	62.24
Nitrogen	1	77.6 (D)	79.1 (E)	78.1 (F)	78.4 (H)	77.7 (G)	78.2
	2	77.9 (E)	79.2 (G)	78.8 (D)	76.8 (F)	76.2 (H)	77.8
	3	75.4 (F)	78.4 (H)	79.5 (G)	78.5 (D)	78.0 (E)	78.0
	4	78.1 (H)	79.0 (F)	78.4 (E)	78.8 (G)	77.2 (D)	78.3
	5	75.2 (G)	79.3 (D)	78.5 (H)	77.8 (E)	77.3 (F)	77.6
	Means	76.8	79.0	78.7	78.1	77.3	77.97
Ether Extract	1	89.4 (D)	88.6 (E)	86.5 (F)	86.2 (H)	87.8 (G)	87.7
	2	88.1 (E)	88.1 (G)	87.9 (D)	85.8 (F)	84.7 (H)	86.9
	3	88.5 (F)	84.2 (H)	88.8 (G)	87.6 (D)	86.8 (E)	87.2
	4	84.7 (H)	88.1 (F)	86.1 (E)	88.0 (G)	85.1 (D)	86.4
	5	80.3 (G)	86.3 (D)	82.3 (H)	83.8 (E)	85.5 (F)	83.6
	Means	86.2	87.1	86.3	86.3	86.0	86.37
Crude Fibre	1	39.8 (D)	35.8 (E)	34.8 (F)	40.7 (H)	30.7 (G)	36.4
	2	37.5 (E)	36.9 (G)	36.4 (D)	33.8 (F)	33.0 (H)	35.5
	3	39.9 (F)	42.2 (H)	38.0 (G)	36.1 (D)	30.9 (E)	37.4
	4	46.9 (H)	40.6 (F)	39.1 (E)	37.3 (G)	37.3 (D)	40.2
	5	45.9 (G)	46.1 (D)	45.6 (H)	35.0 (E)	34.1 (F)	41.3
	Means	42.0	40.3	38.8	36.6	33.2	38.18
N-free Extract	1	68.2 (D)	65.2 (E)	63.3 (F)	64.0 (H)	62.3 (G)	64.6
	2	64.2 (E)	65.4 (G)	64.0 (D)	61.3 (F)	60.9 (H)	63.2
	3	65.8 (F)	66.5 (H)	66.3 (G)	64.6 (D)	63.8 (E)	65.4
	4	67.3 (H)	66.1 (F)	65.6 (E)	64.6 (G)	63.5 (D)	65.4
	5	67.1 (G)	69.6 (D)	67.9 (H)	63.9 (E)	64.2 (F)	66.5
	Means	66.5	66.6	65.4	63.7	62.9	65.02
Total Carbo-hydrates	1	58.4 (D)	55.1 (E)	53.4 (F)	56.0 (H)	51.4 (G)	54.9
	2	54.9 (E)	55.6 (G)	54.4 (D)	51.8 (F)	51.2 (H)	53.6
	3	56.9 (F)	58.1 (H)	56.5 (G)	54.8 (D)	52.5 (E)	55.8
	4	60.2 (H)	57.2 (F)	56.3 (E)	55.0 (G)	54.3 (D)	56.6
	5	60.2 (G)	62.0 (D)	60.6 (H)	54.4 (E)	54.4 (F)	58.3
	Means	58.1	57.6	56.2	54.4	52.8	55.82

TABLE 3.—COEFFICIENTS OF DIGESTIBILITY OF TOTAL RATION ARRANGED BY PERIODS AND PLANE—*Concluded*

(Coefficients in per cent, animal numbers in brackets)

Nutrient	Period	Plane I	Plane II	Plane III	Plane IV	Plane V	Means
T.D.N. in per cent D.M.	1	69.7 (D)	67.6 (E)	65.9 (F)	67.6 (H)	64.7 (G)	67.1
	2	67.3 (E)	68.0 (G)	67.1 (D)	64.5 (F)	63.8 (H)	66.1
	3	67.8 (F)	68.4 (H)	68.3 (G)	66.8 (D)	65.0 (E)	67.3
	4	69.6 (H)	68.3 (F)	67.3 (E)	66.8 (G)	65.5 (D)	67.5
	5	68.4 (G)	71 3 (D)	69.6 (H)	65.5 (E)	65.7 (F)	68.1
	Means	68.6	68.7	67.6	66.2	64.9	67.22

ANIMAL MEANS

Animal No.	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates	T.D.N.
D	61.0	63.1	78.3	87.3	39.1	66.0	56.8	68.1
E	59.4	61.5	78.2	86.7	35.7	64.5	54.6	66.5
F	59.4	61.3	77.3	86.9	36.6	64.1	54.7	66.4
G	60.0	62.2	78.1	86.6	37.8	65.1	55.7	67.2
H	60.9	63.1	77.9	84.4	41.7	65.3	57.2	67.8

The nitrogen coefficients were irregular. The lowest was obtained at Level I, the next lowest at Level V, and the highest at Level II. From Level II to Level V there was a progressive decrease of 1.7%. The differences between levels were statistically significant. In view, however, of the lack of a progressive decrease from the lowest to the highest level of feeding, and in view of the fact that the decrease from Level II to Level V was less than 2 absolute per cent, it was concluded that the plane of nutrition did not have any material effect on the digestibility of the protein[1] of oil cake meal. As far as the ether extract was concerned, there was no effect of the plane of nutrition upon its digestibility.

The values of the oil cake meal calculated from the mixed rations are given in Table 5. The decrease in digestibility of the total ration has been ascribed entirely to the oil cake since it has been shown previously (1) that the plane of nutrition had no significant effect upon the digestibility of hay. No values have been given for crude fibre since it was impossible to obtain satisfactory coefficients for this nutrient. A column headed "Total Carbohydrates" consisting of the nitrogen-free extract + the crude fibre has been included.

In considering the significance of the decrease in digestibility of the organic matter in the oil cake as the plane increased, it must be borne in mind that the ether extract constituted approximately 14% of the organic matter, the protein approximately 32%, and the total carbohydrates approximately 54%. The most marked effect of the plane was on the carbohydrate fraction. There was no material effect upon the non-carbohydrate fraction.

[1] The term "Coefficient of Digestibility of Nitrogen" is, of course, synonymous with the term "Coefficient of Digestibility of Protein".

TABLE 4.—ANALYSIS OF VARIANCE OF COEFFICIENTS OF DIGESTIBILITY OF TOTAL RATION AND OF T. D. N. IN PER CENT OF DRY MATTER

For $N_1 = 4$, $N_2 = 12$, "z" at P. of 0.05 = 0.5907
"z" at P. of 0.01 = 0.8443

Nutrient	Variance due to	D/F	Sums of squares	Variance	$\frac{1}{2}\log_e V$	z to error
Dry matter	Plane	4	49.06	12.265	1.2534	1.4499
	Period	4	23.26	5.815	0.8802	1.0767
	Animal	4	12.16	3.040	0.5559	0.7524
	Error	12	8.10	0.675	$\bar{1}$.8035	
	Total	24	92.58			
Organic matter	Plane	4	56.26	14.065	1.3218	1.5473
	Period	4	28.16	7.040	0.9758	1.2013
	Animal	4	14.56	3.640	0.6460	0.8645
	Error	12	7.64	0.637	$\bar{1}$.7745	
	Total	24	106.62			
Nitrogen	Plane	4	17.14	4.285	0.7276	0.8932
	Period	4	1.64	0.410	$\bar{1}$.5542	
	Animal	4	3.16	0.790	$\bar{1}$.8821	0.0477
	Error	12	8.61	0.718	$\bar{1}$.8344	
	Total	24	30.55			
Ether extract	Plane	4	3.54	0.885		
	Period	4	52.06	13.015		
	Animal	4	25.94	6.485		
	Error	12	33.89	2.824		
	Total	24	115.43			
Crude Fibre	Plane	4	233.84	58.460	2.0342	1.5703
	Period	4	123.87	30.968	1.7165	1.2526
	Animal	4	110.14	27.535	1.6577	1.1938
	Error	12	30.35	2.529	0.4639	
	Total	24	498.20			
N-Free Extract	Plane	4	55.34	13.835	1.3136	1.4555
	Period	4	29.84	7.460	1.0048	1.1467
	Animal	4	10.81	2.703	0.4972	0.6391
	Error	12	9.03	0.753	$\bar{1}$.8581	
	Total	24	105.02			
Total carbo-hydrates	Plane	4	98.24	24.560	1.6006	1.6247
	Period	4	62.67	15.668	1.3758	1.3999
	Animal	4	28.11	7.028	0.9749	0.9990
	Error	12	11.44	0.953	$\bar{1}$.9759	
	Total	24	200.46			
T.D.N. in per cent of D.M.	Plane	4	53.31	13.328	1.2949	1.6640
	Period	4	10.64	2.660	0.4892	0.8583
	Animal	4	11.51	2.878	0.5285	0.8976
	Error	12	5.74	0.478	1.6309	
	Total	24	81.20			

TABLE 5.—SUMMARY OF CALCULATED COEFFICIENTS OF DIGESTIBILITY AND RESULTING T.D.N. OF OIL CAKE AT DIFFERENT LEVELS OF FEEDING

(Coefficients in per cent, T.D.N. in per cent of dry matter)

Level	Dry matter	Organic matter	Nitrogen	Ether extract	Total carbo-drates*	T.D.N.
I	72.8	76.1	83.7	91.8	68.5	86.7
II	72.8	75.9	86.2	92.8	67.1	87.1
III	71.1	73.9	85.8	92.0	63.7	85.0
IV	68.4	71.1	85.1	91.9	59.0	82.3
V	65.8	68.4	84.1	91.6	54.8	79.8

*Crude fibre + N-free Extract.

It will be noted further that in the range of feeding covered by the first 3 levels, namely, 1 to 3 kilogrammes of oil cake per day, the values of the total digestible nutrients did not change very appreciably. The total carbohydrates, however, did show a marked drop in digestibility throughout.

Attention should be drawn to the high digestibility of the ether extract and the constancy of its digestibility regardless of the level of feeding. At the lowest level the animals were receiving approximately 0.12 kilogrammes and at the highest level 0.6 kilogrammes of ether extract per day.

The results obtained in this paper are at variance with those obtained with a hay-barley ration (2). In that case the most marked effect was on the protein, while the effect on the carbohydrates was almost negligible. No attempt to explain this is given here beyond pointing out that the nature of the carbohydrates in barley differs from that in oil cake. In the former case approximately 95% of the so-called nitrogen-free extract consists of starch, while with oil cake, nitrogen-free extract only contains about 10% starch.

SUMMARY

Five grade Shorthorn steers were fed a ration composed of equal parts of hay and oil cake meal at 5 different levels of feeding. The digestibility of the total carbohydrates of the ration decreased progressively as the plane of nutrition was increased. The magnitude of the change in digestibility was to the order of 4 absolute per cent. It was statistically significant. On the other hand, the digestibility of the non-carbohydrate fraction of the organic matter, that is, protein + ether extract, did not change materially as the level of feeding was increased. The values of the protein were somewhat higher in the middle ranges of feeding than at the lowest and highest levels. The values for ether extract were practically constant throughout.

The total digestible nutrients in the dry matter decreased progressively from the lowest to the highest level of feeding. This decrease was significant and amounted to approximately 4%.

The most marked effect of the plane of nutrition was observed among the 3 highest levels.

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APPENDIX

Table 6.—Chemical composition of feeding stuffs in per cent

Feed	Period	Moisture	Composition of dry matter				
			Ash	Protein*	Ether extract	Crude fibre	N-free extract
		p.c.	p.c.	p.c.	p.c.	p.c.	p.c.
Hay	1	12.89	4.62	8.02	1.70	39.46	46.20
	2	13.28	4.71	8.00	1.83	39.80	45.67
	3	13.06	4.93	8.32	1.82	39.19	45.73
	4	12.46	4.95	8.19	1.88	40.03	44.95
	5	12.32	6.43	7.01	2.22	36.51	47.83
Oil cake meal	1	7.35	5.82	30.45	13.06	8.13	42.54
	2	7.96	5.74	29.65	13.24	8.25	43.12
	3	8.28	5.87	29.78	12.70	8.54	43.11
	4	7.87	5.88	30.19	12.23	8.37	43.33
	5	8.42	5.92	29.87	12.72	8.35	43.14

* Factor for Hay = 6.25 × N.
Factor for Oil Cake Meal = 5.30 × N.

TABLE 7.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)
(Coefficients of hay taken from a previous communication (3))

	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates
PERIOD 1								
Animal D								
In hay	12.000	10.453	9.970	0.134	0.178	4.125	4.829	8.954
In oil cake	12.000	11.118	10.471	0.639	1.452	0.904	4.730	5.634
Total	24.000	21.571	20.441	0.773	1.630	5.029	9.559	14.588
Feces	43.722	8.059	7.231	0.173	0.172	3.029	3.037	6.066
Digested		13.512	13.210	0.600	1.458	2.000	6.522	8.522
Coefficient		62.6	64.6	77.6	89.4	39.8	68.2	58.4
Dig. from hay		5.049	4.945	0.058	0.077	1.997	2.501	4.498
Dig. from oil cake		8.463	8.265	0.542	1.381	0.003	4.021	4.024
Coeff. of oil cake		76.1	78.9	84.8	95.1	0.3	85.0	71.4
Animal E								
In hay	24.000	20.906	19.940	0.268	0.355	8.250	9.659	17.909
In oil cake	24.000	22.236	20.942	1.278	2.904	1.808	9.459	11.267
Total	48.000	43.142	40.882	1.546	3.259	10.058	19.118	29.176
In feces	75.210	17.153	15.450	0.323	0.371	6.458	6.652	13.110
Digested		25.989	25.432	1.223	2.888	3.600	12.466	16.066
Coefficient		60.2	62.2	79.1	88.6	35.8	65.2	55.1
Dig. from hay		10.098	9.890	0.117	0.154	3.993	5.003	8.996
Dig. from oil cake		15.891	15.542	1.106	2.734	−0.393	7.463	7.070
Coeff. of oil cake		71.5	74.2	86.5	94.1	−21.7	78.9	62.7
Animal F								
In hay	36.000	31.360	29.911	0.402	0.533	12.375	14.488	26.863
In oil cake	36.000	33.354	31.413	1.917	4.356	2.712	14.189	16.901
Total	72.000	64.714	61.324	2.319	4.889	15.087	28.677	43.764
In feces	126.676	26.632	24.169	0.508	0.660	9.838	10.536	20.374
Digested		38.082	37.155	1.811	4.229	5.249	18.141	23.390
Coefficient		58.8	60.6	78.1	86.5	34.8	63.3	53.4
Dig. from hay		15.147	14.836	0.175	0.232	5.990	7.505	13.495
Dig. from oil cake		22.935	22.319	1.636	3.997	−0.741	10.636	9.895
Coeff. of oil cake		68.8	71.1	85.3	91.8	−27.3	75.0	58.5
Animal G								
In hay	52.000	45.297	43.204	0.581	0.770	17.874	20.927	38.801
In oil cake	52.000	48.178	45.374	2.768	6.292	3.917	20.495	24.412
Total	104.000	93.475	88.578	3.349	7.062	21.791	41.422	63.213
In feces	181.273	40.021	36.187	0.746	0.864	15.092	15.636	30.728
Digested		53.454	52.391	2.603	6.198	6.699	25.786	32.485
Coefficient		57.2	59.1	77.7	87.8	30.7	62.3	51.4
Dig. from hay		21.878	21.429	0.253	0.335	8.651	10.840	19.491
Dig. from oil cake		31.576	30.962	2.350	5.863	−1.952	14.946	12.994
Coeff. of oil cake		65.5	68.2	84.9	93.2	−49.8	72.9	53.2
Animal H								
In hay	48.000	41.813	39.881	0.536	0.711	16.499	19.318	35.817
In oil cake	48.000	44.472	41.884	2.555	5.808	3.616	18.918	22.534
Total	96.000	86.285	81.765	3.091	6.519	20.115	38.236	58.351
In feces	161.067	33.945	30.520	0.669	0.900	11.935	13.755	25.690
Digested		52.340	51.245	2.422	5.619	8.180	24.481	32.661
Coefficient		60.7	62.7	78.4	86.2	40.7	64.0	56.0
Dig. from hay		20.196	19.781	0.234	0.309	7.986	10.007	17.993
Dig. from oil cake		32.144	31.464	2.188	5.310	0.194	14.474	14.668
Coeff. of oil cake		72.3	75.1	85.6	91.4	5.4	76.5	65.1

TABLE 7.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)

(Coefficients of hay taken from a previous communication (3))

	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates
PERIOD 2								
Animal D								
In hay	35.924	31.153	29.686	0.399	0.567	12.399	14.228	26.627
In oil cake	36.000	33.134	31.232	1.852	4.387	2.734	14.287	17.021
Total	71.924	64.287	60.918	2.251	4.954	15.133	28.515	43.648
In feces	119.578	25.929	23.375	0.478	0.599	9.627	10.268	19.895
Digested		38.358	37.543	1.773	4.355	5.506	18.247	23.753
Coefficient		59.7	61.6	78.8	87.9	36.4	64.0	54.4
Dig. from hay		15.047	14.724	0.174	0.247	6.001	7.370	13.371
Dig. from oil cake		23.311	22.819	1.599	4.108	−0.495	10.877	10.382
Coeff. of oil cake		70.4	73.1	86.3	93.6	−18.1	76.1	61.0
Animal E								
In hay	11.975	10.385	9.896	0.133	0.189	4.133	4.743	8.876
In oil cake	12.000	11.045	10.411	0.617	1.462	0.911	4.763	5.674
Total	23.975	21.430	20.307	0.750	1.651	5.044	9.506	14.550
In feces	37.528	8.686	7.764	0.166	0.197	3.152	3.405	6.557
Digested		12.744	12.543	0.584	1.454	1.892	6.101	7.993
Coefficient		59.5	61.8	77.9	88.1	37.5	64.2	54.9
Dig. from hay		5.016	4.908	0.058	0.082	2.000	2.457	4.457
Dig. from oil cake		7.728	7.635	0.526	1.372	−0.108	3.644	3.536
Coeff. of oil cake		70.0	73.3	85.3	93.8	−11.9	76.5	62.3
Animal F								
In hay	47.898	41.537	39.581	0.532	0.756	16.532	18.970	35.502
In oil cake	48.000	44.179	41.643	2.469	5.849	3.645	19.050	22.695
Total	95.898	85.716	81.224	3.001	6.605	20.177	38.020	58 197
In feces	188.893	37.044	33.458	0.697	0.937	13.358	14.718	28.076
Digested		48.672	47.766	2.304	5.668	6.819	23.302	30.121
Coefficient		56.8	58.8	76.8	85.8	33.8	61.3	51.8
Dig. from hay		20.062	19.632	0.232	0.329	8.001	9.826	17.827
Dig. from oil cake		28.610	28.134	2.072	5.339	−1.182	13.476	12.294
Coeff. of oil cake		64.8	67.6	83.9	91.3	−32.4	70.7	54.2
Animal G								
In hay	23.949	20.769	19.791	0.266	0.378	8.266	9.485	17.751
In oil cake	24.000	22.090	20.822	1.235	2.925	1.822	9.525	11.347
Total	47.949	42.859	40.613	1.501	3.303	10.088	19.010	29.098
In feces	75.380	17.106	15.353	0.312	0.392	6.362	6.569	12.931
Digested		25.753	25.260	1.189	2.911	3.726	12.441	16.167
Coefficient		60.1	62.2	79.2	88.1	36.9	65.4	55.6
Dig. from hay		10.031	9.816	0.116	0.164	4.001	4.913	8.914
Dig. from oil cake		15.722	15.444	1.073	2.747	−0.275	7.528	7.253
Coeff. of oil cake		71.2	74.2	86.9	93.9	−15.1	79.0	63.9
Animal H								
In hay	61.869	53.653	51.126	0.687	0.976	21.354	24.503	45.857
In oil cake	62.000	57.065	53.789	3.189	7.555	4.708	24.606	29.314
Total	123.869	110.718	104.915	3.876	8.531	26.062	49.109	75.171
In feces	262.663	48.085	43.560	0.922	1.308	17.455	19.205	36.660
Digested		62.633	61.355	2.954	7.223	8.607	29.904	38.511
Coefficient		56.6	58.5	76.2	84.7	33.0	60.9	51.2
Dig. from hay		25.914	25.358	0.300	0.425	10.335	12.693	23.028
Dig. from oil cake		36.719	35.997	2.654	6.798	−1.728	17.211	15.483
Coeff. of oil cake		64.3	66.9	83.2	90.0	−36.7	69.9	52.8

TABLE 7.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)

(Coefficients of hay taken from a previous communication (3))

	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates
PERIOD 3								
Animal D								
In hay	47.611	41.392	39.352	0.551	0.757	16.222	18.929	35.151
In oil cake	48.000	44.026	41.442	2.474	5.591	3.760	18.980	22.740
Total	95.611	85.419	80.794	3.025	6.348	19.982	37.909	57.891
In feces	169.480	34.565	31.050	0.651	0.788	12.775	13.411	26.186
Digested		50.854	49.744	2.374	5.560	7.207	24.498	31.705
Coefficient		59.5	61.6	78.5	87.6	36.1	64.6	54.8
Dig. from hay		19.993	19.519	0.240	0.329	7.851	9.805	17.656
Dig. from oil cake		30.861	30.225	2.134	5.231	−0.644	14.693	14.049
Coeff. of oil cake		70.1	72.9	86.3	93.6	−17.1	77.4	61.8
Animal E								
In hay	55.050	47.860	45.501	0.637	0.876	18.756	21.886	40.642
In oil cake	55.500	50.905	47.917	2.860	6.465	4.347	21.945	26.292
Total	110.550	98.765	93.418	3.497	7.341	23.103	43.831	66.934
In feces	217.532	41.522	37.474	0.770	0.972	15.961	15.861	31.822
Digested		57.243	55.944	2.727	6.369	7.142	27.970	35.112
Coefficient		58.0	59.9	78.0	86.8	30.9	63.8	52.5
Dig. from hay		23.116	22.568	0.278	0.381	9.078	11.337	20.415
Dig. from oil cake		34.127	33.376	2.449	5.988	−1.936	16.633	14.697
Coeff. of oil cake		67.0	69.7	85.6	92.6	−44.5	75.8	55.9
Animal F								
In hay	11.903	10.348	9.838	0.138	0.189	4.055	4.732	8.787
In oil cake	12.000	11.006	10.360	0.618	1.398	0.940	4.745	5.685
Total	23.903	21.354	20.198	0.756	1.587	4.995	9.477	14.472
In feces	44.615	8.375	7.533	0.186	0.183	3.003	3.237	6.240
Digested		12.979	12.665	0.570	1.404	1.992	6.240	8.232
Coefficient		60.8	62.7	75.4	88.5	39.9	65.8	56.9
Dig. from hay		4.998	4.880	0.060	0.082	1.963	2.451	4.414
Dig. from oil cake		7.981	7.785	0.510	1.322	0.029	3.789	3.818
Coeff. of oil cake		72.5	75.1	82.5	94.6	3.1	79.9	67.2
Animal G								
In hay	35.708	31.045	29.514	0.413	0.568	12.167	14.197	26.364
In oil cake	36.000	33.019	31.081	1.855	4.193	2.820	14.234	17.054
Total	71.708	64.064	60.595	2.268	4.761	14.987	28.431	43.418
In feces	107.014	25.014	22.403	0.465	0.535	9.290	9.595	18.885
Digested		39.050	38.192	1.803	4.226	5.697	18.836	24.533
Coefficient		61.0	63.0	79.5	88.8	38.0	66.3	56.5
Dig. from hay		14.995	14.639	0.180	0.247	5.889	7.354	13.243
Dig. from oil cake		24.055	23.553	1.623	3.979	−0.192	11.482	11.290
Coeff. of oil cake		72.9	75.8	87.5	94.9	−6.8	80.7	66.2
Animal H								
In hay	23.805	20.696	19.676	0.275	0.379	8.111	9.464	17.575
In oil cake	24.000	22.013	20.721	1.237	2.796	1.880	9.490	11.370
Total	47.805	42.709	40.397	1.512	3.175	9.991	18.954	28.945
In feces	88.254	16.490	14.679	0.327	0.503	5.772	6.355	12.127
Digested		26.219	25.718	1.185	2.672	4.219	12.599	16.818
Coefficient		61.4	63.7	78.4	84.2	42.2	66.5	58.1
Dig. from hay		9.996	9.759	0.120	0.165	3.926	4.902	8.828
Dig. from oil cake		16.223	15.959	1.065	2.507	0.293	7.697	7.990
Coeff. of oil cake		73.7	77.0	86.1	89.7	15.6	81.1	70.3

TABLE 7.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Continued*

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)

(Coefficients of hay taken from a previous communication (3))

	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates
PERIOD 4								
Animal D								
In hay	61.843	54.137	51.457	0.709	1.018	21.671	24.335	46.006
In oil cake	62.500	57.581	54.195	3.280	7.042	4.820	24.950	29.770
In total ration	124.343	111.718	105.652	3.989	8.060	26.491	49.285	75.776
In feces	251.764	46.395	41.542	0.911	1.197	16.623	17.978	34.601
Digested		65.323	64.110	3.078	6.863	9.868	31.307	41.175
Coefficient		58.5	60.7	77.2	85.1	37.3	63.5	54.3
Dig. from hay		26.148	25.523	0.309	0.443	10.489	12.606	23.095
Dig. from oil cake		39.175	38.587	2.769	6.420	−0.621	18.701	18.080
Coeff. of oil cake		68.0	71.2	84.4	91.2	−12.9	75.0	60.7
Animal E								
In hay	35.622	31.183	29.639	0.408	0.586	12.483	14.017	26.500
In oil cake	36.000	33.167	31.217	1.890	4.056	2.776	14.371	17.147
In total ration	71.622	64.350	60.856	2.298	4.642	15.259	28.388	43.647
In feces	122.543	25.351	22.742	0.497	0.646	9.291	9.775	19.066
Digested		38.999	38.114	1.801	3.996	5.968	18.613	24.581
Coefficient		60.6	62.6	78.4	86.1	39.1	65.6	56.3
Dig. from hay		15.061	14.701	0.178	0.255	6.042	7.261	13.303
Dig. from oil cake		23.938	23.413	1.623	3.741	−0.074	11.352	11.278
Coeff. of oil cake		72.2	75.0	85.9	92.2	−2.7	79.0	65.8
Animal F								
In hay	23.748	20.789	19.760	0.272	0.391	8.322	9.345	17.667
In oil cake	24.000	22.111	20.811	1.260	2.704	1.851	9.581	11.432
In total ration	47.748	42.900	40.571	1.532	3.095	10.173	18.926	29.099
In feces	83.232	16.619	14.829	0.321	0.369	6.043	6.420	12.463
Digested		26.281	25.742	1.211	2.726	4.130	12.506	16.636
Coefficient		61.3	63.4	79.0	88.1	40.6	66.1	57.2
Dig. from hay		10.041	9.801	0.119	0.170	4.028	4.841	8.869
Dig. from oil cake		16.240	15.941	1.092	2.556	0.102	7.665	7.767
Coeff. of oil cake		73.4	76.6	86.7	94.5	5.5	80.0	67.9
Animal G								
In hay	47.496	41.578	39.520	0.545	0.782	16.644	18.689	35.333
In oil cake	48.000	44.222	41.622	2.519	5.408	3.701	19.161	22.862
In total ration	95.496	85.800	81.142	3.064	6.190	20.345	37.850	58.195
In feces	156.515	34.154	30.725	0.649	0.745	12.760	13.399	26.159
Digested		51.646	50.417	2.415	5.445	7.585	24.451	32.036
Coefficient		60.2	62.1	78.8	88.0	37.3	64.6	55.0
Dig. from hay		20.082	19.602	0.238	0.340	8.056	9.681	17.737
Dig. from oil cake		31.564	30.815	2.177	5.105	−0.471	14.770	14.299
Coeff. of oil cake		71.4	74.0	86.4	94.4	−12.7	77.1	62.5
Animal H								
In hay	11.874	10.394	9.879	0.136	0.195	4.161	4.672	8.833
In oil cake	12.000	11.056	10.406	0.630	1.352	0.925	4.791	5.716
In total ration	23.874	21.450	20.285	0.766	1.547	5.086	9.463	14.549
In feces	40.021	7.906	7.016	0.168	0.236	2.703	3.091	5.794
Digested		13.544	13.269	0.598	1.311	2.383	6.372	8.755
Coefficient		63.1	65.4	78.1	84.7	46.9	67.3	60.2
Dig. from hay		5.020	4.900	0.059	0.085	2.014	2.420	4.434
Dig. from oil cake		8.524	8.369	0.539	1.226	0.369	3.952	4.321
Coeff. of oil cake		77.1	80.4	85.6	90.7	39.9	82.5	75.6

TABLE 7.—CALCULATION OF COEFFICIENTS OF DIGESTIBILITY—*Concluded*

(Collection period of 12 days; weights in kilogrammes; coefficients in per cent)

(Coefficients of hay taken from a previous communication (3))

	Original weights	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	Total carbo-hydrates
PERIOD 5								
Animal D								
In hay	23.568	20.664	19.335	0.232	0.459	7.544	9.884	17.428
In oil cake	24.000	21.979	20.678	1.239	2.796	1.835	9.482	11.317
In total ration	47.568	42.643	40.013	1.471	3.255	9.379	19.366	28.745
In feces	72.007	15.136	13.232	0.305	0.447	5.052	5.882	10.934
Digested		27.507	26.781	1.166	2.808	4.327	13.484	17.811
Coefficient		64.5	66.9	79.3	86.3	46.1	69.6	62.0
Dig. from hay		11.200	10.750	0.113	0.238	4.074	5.752	9.826
Dig. from oil cake		16.307	16.031	1.053	2.570	0.253	7.732	7.985
Coeff. of oil cake		74.2	77.5	85.0	91.9	13.8	81.5	70.6
Animal E								
In hay	47.137	41.330	38.672	0.464	0.918	15.090	19.768	34.858
In oil cake	48.000	43.958	41.356	2.477	5.591	3.670	18.963	22.633
In total ration	95.137	85.288	80.028	2.941	6.509	18.760	38.731	57.491
In feces	187.375	35.079	31.182	0.653	1.056	12.197	14.000	26.197
Digested		50.209	48.846	2.288	5.453	6.563	24.731	31.294
Coefficient		58.9	61.0	77.8	83.8	35.0	63.9	54.4
Dig. from hay		22.401	21.502	0.226	0.476	8.149	11.505	19.654
Dig. from oil cake		27.808	27.344	2.062	4.977	−1.586	13.226	11.640
Coeff. of oil cake		63.3	66.1	83.2	89.0	−43.2	69.7	51.4
Animal F								
In hay	55.975	49.079	45.923	0.551	1.090	17.919	23.474	41.393
In oil cake	57.000	52.201	40.111	2.942	6.640	4.359	22.520	26.879
In total ration	112.975	101.280	95.034	3.493	7.730	22.278	45.994	68.272
In feces	231.734	41.256	36.978	0.794	1.118	14.679	16.457	31.136
Digested		60.024	58.056	2.699	6.612	7.599	29.537	37.136
Coefficient		59.3	61.1	77.3	85.5	34.1	64.2	54.4
Dig. from hay		26.601	25.533	0.268	0.565	9.676	13.662	23.338
Dig. from oil cake		33.423	32.523	2.431	6.047	−2.077	15.875	13.798
Coeff. of oil cake		64.0	66.2	82.6	91.1	−47.6	70.5	51.3
Animal G								
In hay	11.784	10.332	9.668	0.116	0.229	3.772	4.942	8.714
In oil cake	12.000	10.990	10.339	0.619	1.398	0.918	4.741	5.659
In total ration	23.784	21.322	20.007	0.735	1.627	4.690	9.683	14.373
In feces	39.873	8.206	7.120	0.182	0.321	2.535	3.184	5.719
Digested		13.116	12.887	0.553	1.306	2.155	6.499	8.654
Coefficient		61.5	64.4	75.2	80.3	45.9	67.1	60.2
Dig. from hay		5.600	5.375	0.056	0.119	2.037	2.876	4.913
Dig. from oil cake		7.516	7.512	0.497	1.187	0.118	3.623	3.741
Coeff. of oil cake		68.4	72.7	80.3	84.9	12.9	76.4	66.1
Animal H								
In hay	35.353	30.998	29.005	0.348	0.688	11.317	14.826	26.143
In oil cake	36.000	32.969	31.017	1.858	4.194	2.753	14.223	16.976
In total ration	71.353	63.967	60.022	2.206	4.882	14.070	29.049	43.119
In feces	126.008	23.703	20.742	0.474	0.863	7.658	9.327	16.985
Digested		40.264	39.280	1.732	4.019	6.412	19.722	26.134
Coefficient		62.9	65.4	78.5	82.3	45.6	67.9	60.6
Dig. from hay		16.801	16.127	0.169	0.356	6.111	8.629	14.740
Dig. from oil cake		23.463	23.153	1.563	3.663	0.301	11.093	11.394
Coeff. of oil cake		71.2	74.6	84.1	87.3	10.9	78.0	67.1

MICRO-ELEMENT STUDIES WITH SPECIAL REFERENCE TO THE ELEMENT BORON[1]

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The importance of boron in the nutrition of economic plants cannot be too strongly emphasized. The very minute quantities required by the plants make it no less essential for normal growth. If this element is not available in sufficient quantity, the effects on the plants are such as to give rise to disorders which may reduce the value of the crop or even make it worthless.

The poor growth accompanying a deficiency of boron is ample proof that boron is essential for the formation of new tissue and consequently for normal growth. That is, boron is just as essential as any of the major elements and it must receive consideration in any nutritional investigation.

THE ROLE OF BORON IN SOME PLANTS

Literature Review

The importance of boron as an essential element in plant nutrition has become well known from the writings of Warington (30), Brenchley (7, 8, 10), Brandenburg (6), Johnston and Dore (22), Dennis (15) and Dennis and O'Brien (16) and others. The progressive development in the knowledge of this element in its relation to growing plants has been hastened by the findings of numerous investigators.

The actual part that boron plays in the life and growth of a plant has not yet been fully determined. It is known that a deficiency of this element causes disturbances which are usually reflected in the appearance and yield of the plant and that these may be prevented and sometimes cured by small applications of boron.

As early as 1910, Agulhon (1) working with wheat, oats, peas, radishes, etc. found there was an optimum concentration of boron which favoured the growth of each. Greater quantities reduced the chlorophyll content and checked root development.

Schmucker (28) found boron would prevent excessive swelling and bursting of pollen tubes and suggested that it may play some part in the formation of pectin. Dennis and O'Brien (16) also observed a cellular swelling and consequent decrease of inter-cellular spaces as a result of insufficient boron. Furthermore, the discolouration and swelling of the middle lamella, followed by the discolouration and breakdown of cell walls as a result of boron starvation, strongly indicates that boron plays a definite part in the formation of pectin substances and in cell rigidity.

Some workers think there may be a relationship between calcium and boron, but so far no exact relation has been found.

Dennis and O'Brien (16) indicate that boron plays a part in the translocation of carbohydrates. Evidence is presented by Johnston and

[1] Read before the 1938 Summer Meeting of the American Association for the Advancement of Science held at the Central Experimental Farm, Ottawa, Ont., and revised to February 1, 1940. Contribution No. 523 from the Division of Horticulture, Experimental Farms Service. Prepared with the co-operation of the Division of Chemistry, Science Service.

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Dore (22) from their work on tomatoes which strongly supports this point of view.

From experiments on grapefruit and orange trees, Haas and Klotz (20) conclude that boron is essential to cell division in the meristematic tissues and in the cambium. A deficiency of boron caused the cambium and part of the phloem to disintegrate, and gum was formed which permeated through to the exterior. Recovery was obtained by supplying boron. An accumulation of carbohydrates in the leaves and destruction of the phloem in boron deficient plants point to the effect of a lack of this element upon carbohydrate translocation.

Schmidt (27) as a result of work with barley sprouts growing in sand claims that boron influences the assimilation of nitrate nitrogen. Using different sources of nitrogen for plants growing in sand he observed a higher nitrate nitrogen content in the boron deficient plants than in those receiving boron. Also he observed that the nitrate nitrogen supply remaining in the sand increased steadily with the amount of boron supplied in the nutrient solution.

Schropp and Scharrer (29) with mangolds found higher nitrogen in the leaves than in the roots of healthy plants but that the reverse held true for badly rotted (boron deficient) plants. On alkaline soil, boron tended to increase the nitrogen content of roots and leaves, but on acid soil this effect was concealed in the roots by the reduction in the amount of rot but was still apparent in the nitrogen content of the leaves. This difference in the findings of Schmidt (27) and those of Schropp and Scharrer (29) may possibly be due to the diversity of the two types of plants used.

Results Obtained at the Central Experimental Farm

The first foliage symptom of boron deficency in turnips appears as the typical change in colour described by Hill and Grant (21). This discolouration occurs first at the margins of the older, lower leaves, gradually extending in towards the main rib and the base of the leaf and finally extending to the younger leaves higher up. One of the outstanding results of their work was the very low ash content in the dry matter of the high boron roots as compared to the low boron roots. This supports the conclusions of Dennis and O'Brien (16) and Johnston and Dore (22) that insufficient boron interferes with translocation in the plant.

Ferguson, Foster and Horton in unpublished work on turnips growing in sand found that plants could be starved for boron during their first month in sand and then brought to normal size and health by introducing boron into the feeding solution at the rate of 1.5 p.p.m. Plants starved for boron during the first two months developed a normal external appearance but possessed a small amount of brown heart. When starved for three months before receiving boron, the roots were small, unhealthy looking and badly affected with brown heart. The reverse of this series showed that plants which received boron during the first month only developed very small badly affected roots. Plants receiving boron for the first two months produced much larger and better roots but still badly affected with brown heart. When the boron feedings were continued for three months, the plants produced normal-size roots with a moderate amount of brown heart. It is evident from these results that feeding boron is of more benefit in the later life of the plant than in the early stages.

It is likely that the time of greatest root development coincides with the time during which the plant has its greatest need for boron.

Similar treatments, but with boron applied as a spray on the foliage instead of through the roots, supported the above findings in a lesser degree and showed that boron could be absorbed by the leaves and transported through the plant.

Spectrographic analysis of the plant material showed the boron level in the leaves of plants receiving a normal supply of 1.5 p.p.m. of boron in the feeding solution during the experiment to be higher than that of the roots, which in turn had a higher concentration than the leaf stalks. Plants receiving no boron did not show this difference; there was a tendency for the old leaves, root and leaf stalks to approach a common level. In contrast to this, the young leaves showed a tendency towards a higher boron level. It is possible the young leaves may be able to draw upon the boron supply in the older tissues to satisfy their own requirements. This is supported by finding that plants which have been starved for boron during the early months in sand show an earlier and greater increase in the boron content of the younger leaves than in the other regions when boron was finally supplied in the nutrient solution.

Work by Phillips (26) at the Division of Horticulture showed that the boron supply influenced the respiration rate of tomatoes. He found that fruit from plants receiving a normal supply of boron produced a type of respiration curve usually associated with good keeping qualities. Fruit from low boron and high boron plants showed higher and more irregular rates of respiration usually associated with poor keeping qualities.

Boron Applications and Their Effect on the Boron Content of Apples and Leaves

During 1936, cork and drought spot disorders were quite prevalent in Ontario and Quebec and it was important to get a rapid, simple method of applying boron to the trees without causing injury. At the Horticultural Division, groups of young McMahon White trees were sprayed weekly with boric acid solutions. Leaves, picked from the ends of the branches six days after each spray application, were analysed spectrographically by the Division of Chemistry for boron content. An 0.23% boric acid spray solution gave an increase from 6.25 p.p.m. of boron in untreated leaves to 37.5 p.p.m. after two sprays and to 100 p.p.m. after three sprays. Spraying with an 0.34% boric acid solution produced greater increases in the boron content, but after the second spray it was found to be injurious, resulting in brown, scorched patches of leaf tissue.

Applying an 0.23% boric acid solution in a lime sulphur spray showed by analysis that the other spray ingredients did not interfere with the absorption of boron. The results for one and two sprays were 25.5 and 37.5 p.p.m. of boron respectively while the check trees contained 12.5 p.p.m. of boron.

These experiments demonstrated that the leaves could readily absorb boron from spray solutions. The following year experiments were conducted at the Hendricks' Orchard to determine the value of spraying and other methods of applying boron in actually increasing the boron content of the fruit apart from the leaves. In the meantime McLarty (23) found that injections of more than 0.48 gram borate per one hundred square

centimetres of trunk cross-sectional area was sufficient to eliminate drought spot, and 1.83 grams eliminated corky core. Askew and Chittenden (3) injected borax into trees and found that 2.5 grams per tree was sufficient to prevent internal cork. Analysis of fruit from injected trees showed an increase in the boron content as the amount of borax injected was increased. They also sprayed using 0.1, 0.5 and 1.0% solutions of borax; the boron content of the fruit increased with the concentration of the spray solution and control of internal cork was realized from every spray. They recommended for growers, as a result of this work, the 0.5% borax spray, preferably applied in two sprays of 0.25% concentration about 3 weeks apart.

During the investigations by the Division of Horticulture at Hendricks' Orchard, Trenton, Ontario, a number of different boron treatments were made. At harvest time (1937) samples of fruit were picked for examination and analysis. Although practically no cork or drought spot was found the boron analyses produced very interesting information for some treatments as shown in Table 1.

TABLE 1.—TOTAL BORON CONTENT OF APPLES FROM TREES RECEIVING DIFFERENT BORON TREATMENTS

Treatment	No. of trees sampled per treatment	Average boron content of fruit samples, p.p.m. on dry basis
No treatment	19	17.24
Boric acid (0.25%) spray—2 sprays, 1937	20	41.00
Borax (0.25%) spray—2 sprays, 1937	8	37.50
Boric acid broadcast—1 lb. per tree, Fall 1936	12	40.80
Boric acid broadcast—1 lb. per tree, Spring 1937	12	25.60
Boric acid deep drilled into ground—1 lb. per tree, Spring 1937	2	27.50
Borax deep drilled into ground, 25 oz. per tree, Spring 1937	2	22.50
Boric acid injected into trunk 20 grams per tree, Spring 1937	12	38.40

The spray applications were made in the regular spray mixtures of lime sulphur and lead arsenate at the time of calyx stage and second cover stage applications about one month apart. The deep drilled applications were made about 2 feet deep in 18 holes randomized within an 11-foot radius from the trunk.

The influence of each treatment is clearly seen in the boron content of the fruit samples. The large concentration of boron resulting from the spray applications clearly indicates that the trees can absorb boron through the leaves and transport it to other regions where it is needed. It would seem, from these results, that boric acid is a little more efficient than borax in raising the boron content of the fruit.

The analysis of leaf samples from the same tree did not show these marked differences. The same observation was made by Askew and Chittenden (3). Their conclusion is that a luxury concentration of boron in the leaves is reduced to a normal level as the season progresses.

BORON CONTENT IN SOME SOILS

Investigational work by the Division of Horticulture and the Ontario Department of Agriculture involved an intensive survey and study of the Hendricks' Orchard at Trenton, Ontario, which was very badly affected with cork and drought spot in 1936. A soil survey disclosed 7 soil types present. Composite soil samples were taken before any treatments were made from areas showing a high amount of cork and from areas showing a low amount of cork in each soil type and analysed for boron. There is some difference between the boron content of high and low cork areas within the same soil type with the greater concentration of boron in the soils where the amount of cork was lowest.

TABLE 2.—THE RELATION BETWEEN THE WATER SOLUBLE BORON CONTENT AT DIFFERENT DEPTHS AND THE OBSERVED AMOUNT OF CORK FOUND IN 1936 WITHIN THE DIFFERENT SOIL TYPES IN HENDRICKS' ORCHARD, TRENTON, ONTARIO

Soil type	Observed amount of cork	Concentration of boron in p.p.m.				
		0–6 in.	6–18 in.	18–30 in.	30–42 in.	Average
Bondhead sandy loam	Med. high 42%	0.43	0.13	0.18	0.13	0.22
	Low 11%	0.50	0.18	0.18	0.18	0.26
Brighton sand	High 94%	0.43	0.15	0.13	0.10	0.20
	Med. low 19%	0.55	0.18	0.13	0.10	0.24
Trenton silt loam	High 94%	0.43	0.13	0.13	0.10	0.20
	Med. 28%	0.50	0.18	0.18	0.13	0.25
Bondhead loam	High 99%	0.43	0.13	0.13	0.13	0.21
	Med. 35%	0.43	0.15	0.15	0.15	0.22
Durham silt loam	Med. high 50%	0.43	0.13	0.15	0.18	0.22
	Med. low 19%	0.55	0.13	0.13	—	0.27
Bottom land	Med. high 36%	0.38	0.18	0.18	0.13	0.22
	Low 4%	0.63	0.18	0.18	0.13	0.28
Frontenac	Med. 19%	0.43	0.18	0.13	0.13	0.22

These investigations are being continued through several counties in that district and when completed may show an influence of soil type on the prevalence of cork and drought spot and the availability of boron.

In the annual report of the Division of Chemistry for 1934–5–6 (2) reference is made to the boron content of soils from limed and unlimed fertilizer plots at the Experimental Station, Kentville, Nova Scotia. As shown in Table 3, the limed plots in general possess a higher water-soluble boron content than the unlimed plots. Yet every limed plot showed considerable cork or cork and drought spot present in 1937 whereas all the unlimed plots were healthy except one which had a very slight amount of cork.

In Eastern Canada boron deficiency disorders are more often found on high lime or alkaline soils. The difference in pH between the healthy (unlimed) and affected (limed) plots support this obersvation. Yet, the pH of these soils cannot be considered high.

TABLE 3.—AVERAGE pH AND BORON[1] CONTENT OF THE SOIL OF VARIOUS FERTILIZER PLOTS, KENTVILLE EXPERIMENTAL STATION

	A_1		A_2		B_1		B_2		Average of A's and B's	
	Boron	pH	Boron	pH	Boron	pH	Boron	pH	Boron	pH
Limed plots	.40	6.3	.12	6.1	.15	5.8	.14	5.1	.20	5.8
Unlimed plots	.21	5.3	.12	5.1	.12	5.1	.11	5.1	.15	5.15

[1] Water soluble boron in parts per million.

Soil horizons: A_1 = 8–12 inches; A_2 = 0–8 inches; B_1 = 9–11 inches; B_2 = 10–20 inches.

BORON REQUIREMENTS OF APPLE TREES

It is difficult to say from the information available, the exact amount of boron required annually by an individual tree or for an acre of orchard. Askew and Chittenden (3) estimate that the fruit and leaves from an acre of orchard would contain 44 grams of boron or approximately 14 ounces of borax. They feel that an application of 50 lb. of borax per acre should satisfy the requirements of the trees.

Blair (4) determined the weight of tree, size of head and number of leaves for an average eight-year old Bramley seedling on M XIII root-stock. Using his results it was estimated that a McIntosh tree with a spread of approximately 24 feet would weigh about 1,100 lb. Trees used in the nutritional experiments at the Horticultural Division weigh about 7 lb. and receive during a growing season 0.015 gram of boron. At this rate a tree of 1,100 lb. would require 2.35 grams annually or 94 grams of boron per acre of 40 trees.

Fisher (18) found that 100 sq. cm. of leaf area with an average leaf size of 12.84 sq. cm. produced an average of 0.075 lb. of apple. Therefore, a tree bearing 15 bushels of apples would require 62,300 leaves weighing approximately 82 lb. on the basis of 100 leaves weighing 60 grams. With a boron content of 2.7 p.p.m. in the fresh fruit and 13.4 p.p.m. in the fresh leaves, this would mean an annual requirement of 49.6 grams of boron per acre of 40 trees. This amount agrees reasonably well with that estimated by Askew and Chittenden (3). Probably the amount required for all parts of the tree would be 44 grams to 90 grams of boron per acre or 14 to 28 ounces of borax.

In 1937, Spy trees at Trenton, Ontario, were given soil applications as high as 4 lb. of boric acid or 6.25 lb. of borax per tree without harmful effects although this rate is 125 to 250 times the estimated requirements. Even leaf samples taken towards the end of the season showed no higher boron content than the control samples. The only observed injury resulting from these heavy applications was a killing of grass and weeds at the base of the trees.

The fixation of boron in the soil may readily offset any toxic effect. This possibility is suggested from the results in Table 2. In fact it would seem that liming may be used as a control for toxic conditions due to excess boron.

McLarty and Wilcox (24) recommend soil applications of 8 oz. boric acid per tree equivalent to about 30 lb. of borax per acre of 40 trees. This furnishes 15 to 30 times the estimated requirements.

As mentioned previously two sprays containing 0.25% borax will control cork and drought spot. On the basis of 5 gallons per tree and 40 trees per acre this would give a borax application of 10 lb. per acre. This is much less than the rates recommended for soil application. The borax is brought into direct contact with the trees and avoids the possibility of boron fixation in the soil.

Whether continued annual spray applications would produce a toxic condition cannot be stated as yet. That there is an excess of boron in the spray may be gathered from the fact that Askew and Chittenden (3) obtained control of cork with only one spray application of 0.1% borax solution. This would give an application of 2 lb. of borax per acre of 40 trees and this agrees with the estimated annual requirements.

THE LIME-BORON RELATIONSHIP

The widely accepted fact that lime increases or aggravates at least some of the disorders due to insufficient boron has called forth a theory in explanation of this observation. The theory is that boron becomes tied up with calcium, probably forming calcium borate which is but slightly soluble. Dry soil conditions or any other factors which may decrease the soil solution will necessarily reduce the amount of calcium borate in solution in the soil and thereby bring about a boron deficiency condition in the plants growing there.

Warington (31) has obtained results with bean plants which strongly indicate a relationship existing between the absorption of calcium and boron. Taking into consideration the reduced growth and vigour of the plants suffering from boron deficiency she found that more calcium was absorbed when the nutrient solution was not renewed than when the solutions were renewed. But when boron was removed from the nutrient solution the reverse was the case. She suggests the presence of complete nutrients and their frequent renewal delays the appearance of boron deficiency symptoms and probably accounts for the difference in calcium absorption.

Brenchley and Warington (9) with leguminous plants found that the chemical combination of boron did not interfere with its action. Even the so-called insoluble borates furnished sufficient boron to the plants.

Coulson and Raymond (13) reduced brown heart by increasing the acidity of the soil with hydrochloric acid from pH 6.1 to 5.2, while raising the pH of the same soil to 7.2 with either sodium hydroxide or lime increased its severity.

This would indicate that lime itself may not increase the disorder but that the high pH usually accompanying a high lime condition may be the explanation of this observation.

Naftel (25) found that excessive liming of a loamy sand soil resulted in injury to such plants as vetch, turnips, oats, cabbage, tomatoes and soybeans. The addition of basic slag even though it rendered the soil quite alkaline did not result in overliming injury. The addition of boron compounds to the excessively limed soils effectively prevented injury.

He claims that the theory of insoluble borates being formed is untenable. He has obtained evidence which indicates that the liming of acid soils stimulates bacterial activity until there is competition between the soil micro-organisms and the higher plants for nutrients present in small amounts.

In contrast to this plausible theory Brioux and Jouis (11) found a greater fixation of boron when a weak solution of borax was allowed to percolate through a calcareous soil than took place with an acid soil. However, other investigators (5) were unable to duplicate these results.

At the Horticultural Division turnip plants growing in sand were supplied with 1.5 and 2.5 p.p.m. of boron as sodium borate and calcium borate in the feeding solution. In addition, the plants were grown under normal and low moisture conditions with and without calcium carbonate in the sand. During growth some plants showed some very slight foliage symptoms indicative of boron deficiency which the plants later grew out of and the symptoms gradually disappeared. These symptoms were not correlated with any treatment beyond the fact that they were a little more common and were later in disappearing from those plants receiving calcium borate.

The roots presented a clean healthy external appearance. On cutting through them those supplied with sodium borate were clean and healthy with the exception of a few small spots with a water soaked appearance in the flesh at the necks of three roots. These were negligible. Where calcium borate was supplied almost 50% of the roots showed some effect from a few water soaked spots to severe brownheart. However, there was no correlation with any of the other treatments.

This would indicate that boron deficiency troubles may be greater when calcium borate is the source of available boron. The acidity of the unlimed series was pH 6.0 to 7.0 while the sand in the limed pots showed a pH of 8.7 to 9.3. The increase in disease found by Coulson and Raymond (13) to accompany an increased alkalinity did not take place here. Whether the amount of brown heart or the number of roots affected would have been reduced if the sand had been made acid is not known.

SYMPTOMS OF BORON DEFICIENCY

An insufficient supply of boron will cause disorders which are often manifested by characteristic symptoms. Many of these symptoms have been encountered in past years, but the cause and control were unknown until recent investigations showed that they were expressions of a deficiency of boron and could be corrected by applications of boron compounds to the soil.

Nutritional investigations at the Horticultural Division have permitted observation and recording of symptoms of disorders due to boron deficiency.

Turnip

The severity of the symptoms due to boron deficiency has been shown by Hill and Grant (21) to coincide with the amount of available boron. The general stunted appearance of the plant, the purplish yellowing of the foliage and drying back from the margins, the cracking of the leaf

stalks, and the appearance of brown and hollow heart in the root are all well known symptoms due to insufficient boron.

Cauliflower

A small curd, brown in colour, poorly developed with brownish areas of a water-soaked appearance in the flesh of the curd and poorly developed, and distorted leaves immediately around the curd accompany boron

FIGURE 1. Turnip plants showing effect of insufficient boron. *Left*—Boron concentration of 1.0 p.p.m., normal. *Centre*—Boron concentration of 0.25 p.p.m. *Right*—Lacking boron.

FIGURE 2. The effect of boron on cauliflower plants. *Left*—Boron concentration of 0.25 p.p.m., normal. *Right*—Lacking boron.

deficiency. This disorder has been found by Dearborn *et al.* (14) and Chandler *et al.* (12) who corrected it by applications of a small amount of borax to the soil. Ferguson (17) found a concentration of 0.25 p.p.m. of boron in the feeding solution was sufficient to prevent these symptoms.

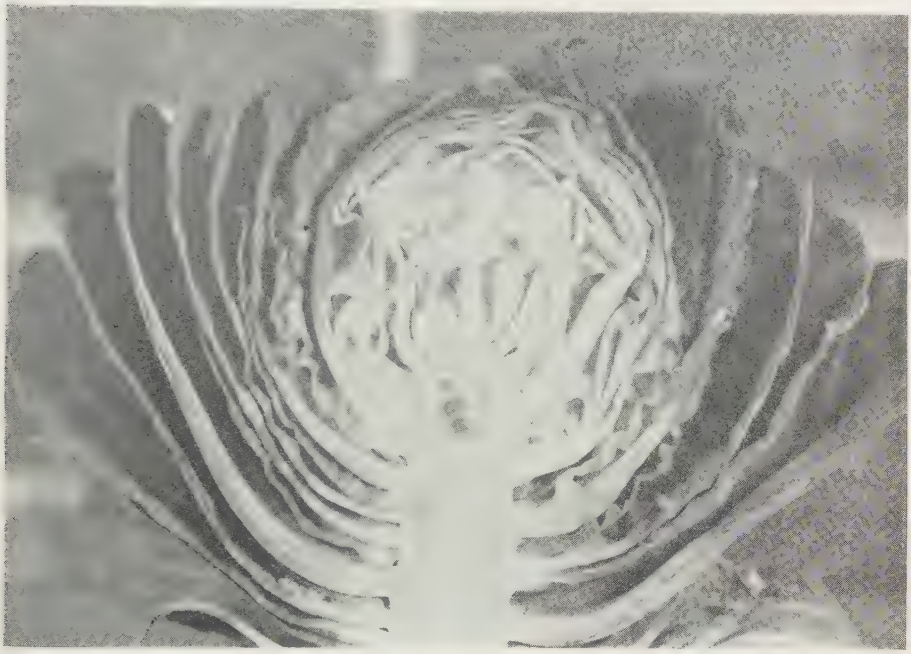

FIGURE 3. Boron deficiency in cabbage showing as brownish spots with water-soaked appearance in the flesh of the stalk and at the base of the leaves.

Cabbage

No external symptoms due to boron deficiency were found on cabbage, var. Golden Acre, grown in sand at the Horticultural Division. But on cutting through the head, brownish areas with a water-soaked appearance were found in the flesh at the base of the leaves, just where they joined the main stalk. As with cauliflower, a concentration of 0.25 p.p.m. of boron in the feeding solution was sufficient to prevent these symptoms.

Corn

Sweet corn, var. Golden Bantam, grown in sand showed no external symptoms due to boron deficiency. But the ears from boron deficient plants showed a marked, corky-brown, narrow band extending along the outer edge of the cobs at the base of the kernels. This area in ears from boron fed plants was a clean, greenish-white, healthy colour.

Celery

The effect of insufficient boron is very marked in celery. Very poor growth, yellowing and dying off of the leaves and brown coloured cracking along the stalks are readily associated with a deficiency of boron.

FIGURE 4. Boron deficiency in sweet corn. *Left*—Lacking boron, note corky brownish areas directly at base of kernels. *Right*—Normal.

Tomato

Boron deficiency in tomatoes shows up in the dwarfed or compressed appearance of the plants. The compression is more pronounced towards the top of the plant. In addition, the upper leaves gradually turn an orange yellow with some purplish browning of the leaf margins and mottling on the leaves. These conditions gradually become more pronounced until the top of the plant dies and all the leaves have become orange yellow with purplish brown patches.

The fruits frequently express symptoms such as a scurfiness or roughness sometimes developing into a brown or blackish cork-like area around the stem end. A type of greenish blotchy ripening is frequently more common on boron deficient plants than on others.

Apples

The physiological disorders, drought spot and cork have become well known in recent years. Drought spot shows as light brown areas of irregular size and shape restricted to the surface of the fruit and may resemble sun scald or spray burn in some respects. As the fruit matures, the spots may become roughened and cracked with a hard, cork-like appearance.

The cork disorder is more common and is usually seen as brown, cork-like spots scattered close around the core, or if there are a large number of these spots, they may fuse into an irregular, brown, cork-like band around the core. This type of disorder is called corky core and is only seen when

FIGURE 5. Brown cracking on celery stalk due to boron deficiency.

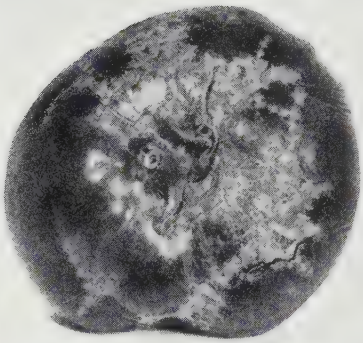

FIGURE 6. Scurfiness and blackening around the stem end of tomatoes associated with insufficient boron.

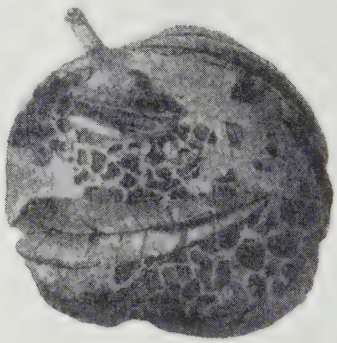

FIGURE 7. Drought spot on McIntosh apple showing as rough brown areas and cracking of the fruit.

FIGURE 8. McIntosh and Fameuse apples showing cork. This type of cork is usually called Corky Core and is not detectable externally.

the apple is cut open. In some cases the brown, cork-like spots may extend through the flesh and even to the surface of the fruit giving it an indented or crinkled appearance, and sometimes result in large, brown areas of dead flesh. This is usually referred to as internal cork.

An excess boron condition, caused by injecting solid boric acid crystals into the trunks of Ben Davis and Fameuse trees can produce unmistakable symptoms on the foliage. A yellowing develops at the base of the leaf and extends up on both sides of the main rib gradually becoming narrower and tapering off part way up the main rib.

Another effect of an excess boron administration to the tree by solid injection has been found by Gloyer (19) on Baldwin trees. A yellow streak formed in the new spring bark and soon turned brown. The streak took a spiral path up the tree and usually ended in one of the top branches. Any

branch in its path was killed. The longest streak formed was twelve feet. Varieties may differ in this respect. Northern Spy trees similarly treated developed cankers about 12 inches long at the point of injection.

Chrysanthemums

The most pronounced symptoms showing on Marie Adelaide, a bush type chrysanthemum, grown under deficient boron conditions in sand at the Horticultural Division was a definite up-curling of the flower petals

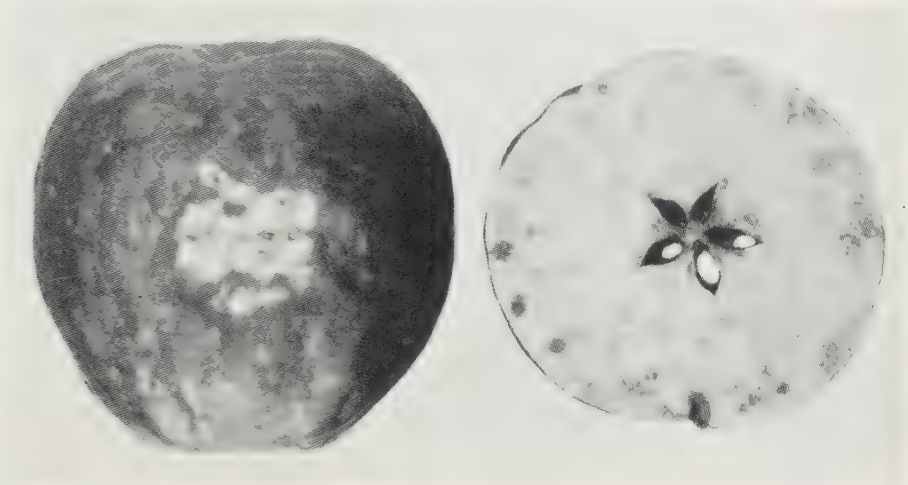

FIGURE 9. Fameuse apples showing the external and internal appearance of Internal Cork.

FIGURE 10. Yellowing extending up both sides of the main rib of Fameuse leaves indicating a high boron condition.

FIGURE 11. The effect of boron on chrysanthemum flowers, Var. Marie Adelaide. A nutrient solution lacking boron produced flowers with incurved petals as shown at the left. With 1.0 p.p.m. of boron in the feeding solution normal flowers were produced as seen at the right.

instead of the usual down-curling. The symptom produces quite a pleasing appearance. A chlorosis or yellowing of the leaves and a gradual dying back from the tips of the leaves was found to accompany a deficiency of boron.

Antirrhinums

Although snapdragons grown under boron deficient conditions did not show any deficiency symptoms yet the effect was clearly expressed in the number of blossoms produced, namely 30% less than the yield from plants receiving a normal solution. All the various deficient series except deficient nitrogen and deficient phosphorus produced more blossoms than the boron deficient series.

Carnations

Here again no boron deficient symptoms were observed but where boron and manganese were supplied together to carnations in sand there was a 5% greater yield and almost 70% less calyx splitting.

OTHER MINOR ELEMENTS

Other minor elements have been studied in experiments at the Horticultural Division by H. Hill (20A) with some interesting results.

Manganese

Concentrations of 2.0 to 4.0 p.p.m. of this element in the nutrient solution produced a slightly stunted appearance of tomato plants and some

mottling of the foliage. A small decrease in yield of fruit was also apparent.

A deficiency of manganese was accompanied by a droopiness and chlorosis of the foliage of chrysanthemums and a slightly reduced yield of blossoms from snapdragon plants. Potato plants were stunted and the foliage had a light green colour with some yellowing and curling of the leaf margins.

Manganese and boron, as mentioned previously, increased the number of carnation flowers and decreased the amount of calyx splitting.

Copper

Addition of copper as copper sulphate to give a concentration of 0.1 p.p.m. in the nutrient solution produced no change in celery or turnip plants. Various concentrations of copper up to 1.0 p.p.m. produced no symptoms on tomato plants but were accompanied by a corresponding decrease in the yield of fruit.

Zinc, Uranium, Strontium

These elements were supplied in concentrations up to 0.5 p.p.m. in the nutrient solution without the appearance of any disorders on tomato plants. But in every case there was a decrease in yield of fruit as the concentrations of these elements were raised.

SUMMARY

The evidence indicates that a deficiency of boron causes disturbances which affect the cell structure and interfere with translocation of materials in the plant.

Turnips lacking boron during the early stages developed larger and healthier roots than plants lacking boron during the later stages of growth. It is likely that turnips require boron most when their root development is greatest.

Analysis of turnip plants receiving 1.5 p.p.m. of boron showed the highest concentration of boron in the leaves, less in the roots, and least in the leaf stalks, whereas plants receiving no boron showed a tendency for the boron level in the mature leaves, roots and stalks to approach a common level.

There is a possibility that young leaves, for a time at least, can draw upon the boron stored in other regions of the plant.

Low boron and high boron fed tomato plants produced fruit showing high, irregular respiration rates associated with poor keeping qualities.

Boron in sprays applied to the foliage of turnips and apple trees was absorbed and utilised by the plants.

Including borax or boric acid in 2 of the regular spray mixtures for apple trees was one of the most efficient methods of application to raise the boron content of the fruit for the prevention of cork and drought spot.

The application of lime to orchard plots was accompanied by an increase in the amount of cork and drought spot. The higher boron content in the soil from the limed plots would indicate a fixation of boron.

Boron analysis of 6 different soil types showed a relationship between the amount of water-soluble boron and the amount of cork within each soil type.

It is estimated that an acre of productive apple orchard will require between 44 and 90 grams of boron or 14 to 28 oz. of borax annually.

The effect of lime upon the boron content of the soil is uncertain. Experimental evidence indicates 3 possibilities:—

(a) Lime may fix boron into some insoluble or slightly soluble form.

(b) Lime increases the pH of the soil and may thereby reduce the availability of the boron or reduce the ability of the roots to absorb boron.

(c) Lime may stimulate the growth of soil micro-organisms until there is competition between them and the plants for the supply of available boron.

Some symptoms and effects of insufficient and excess boron are described for such plants as turnip, cauliflower, celery, tomato, apple, chrysanthemum, cabbage and corn.

Manganese is necessary for normal growth of many plants but a small excess was observed to affect the foliage and yield of tomato plants.

Additions of copper, zinc, uranium and strontium supplied in very small quantities were accompanied by reduced yields of fruit from tomato plants.

ACKNOWLEDGMENT

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THE POLLINATION OF THE PLUM ON VANCOUVER ISLAND, BRITISH COLUMBIA[1]

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INTRODUCTION

Pollination in plums has been studied and reported on by workers in many sections of North America. It has been found that varieties differ widely in their ability to set fruit from self-pollinations. The plum is widely grown throughout the whole region of the Pacific Coast and ranks high in importance among tree fruits.

This study was undertaken in 1932 to secure data on the ability of varieties to set fruit from self-pollinations, and to determine effective pollenizers for those commercial varieties that might require cross-pollination. In order that flowers may be fertilized and fruit set there must be a supply of compatible pollen and an adequate number of insect pollinators to ensure that this pollen be transferred to the stigmas of the flowers. The honey bee has been found to be the chief agency by means of which this transfer is effected. Causes of unfruitfulness in plums, other than those involved in the question of self- and cross-compatibility, are outside the scope of this article.

LITERATURE REVIEW

A survey of literature on pollination reveals the fact that varieties of major importance in one region may be of minor or no importance in another. Mallard, Peach and Victoria, while popular varieties on Vancouver Island, have not been used in pollination studies in some other plum-growing areas. Hendrickson (5) working with popular varieties in California lists but 2 or possibly 3 varieties recommended by this Station.

Dorsey (1) found self-sterility in 7 plum species and that self-sterility was constant in expression. According to Goff (2) the pollen bearing capacity of different varieties of plums does not vary much. Waugh (6) found that the necessity of cross-pollination is very positive in many varieties and species of plums. Dorsey (1) states that self-sterility is so general in the plums that cross-pollination, except in certain varieties of *P. domestica*, is essential to fruitfulness.

BLOSSOMING DATES OF PLUM VARIETIES

In order that there may be free cross-pollination there must be considerable overlapping in blooming periods. The earliest varieties to flower are practically through when the latest begin. Time of flowering may vary greatly from year to year but varieties retain the same relative position whether the season be early or late. Blooming dates (Figure 1) for a 10-year period (1929–38) show much overlapping in blooming periods. Earliest

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and latest varieties to flower could not be expected to cross-pollinate effectively, but in most varieties there is sufficient overlapping to ensure a supply of viable pollen when the stigmas are receptive. Temperature and general weather conditions influence the length of the blooming period.

There are many factors causing unfruitfulness in plums, such as high and low temperatures, wind, rain, humidity, amount of sunshine, frost, etc.

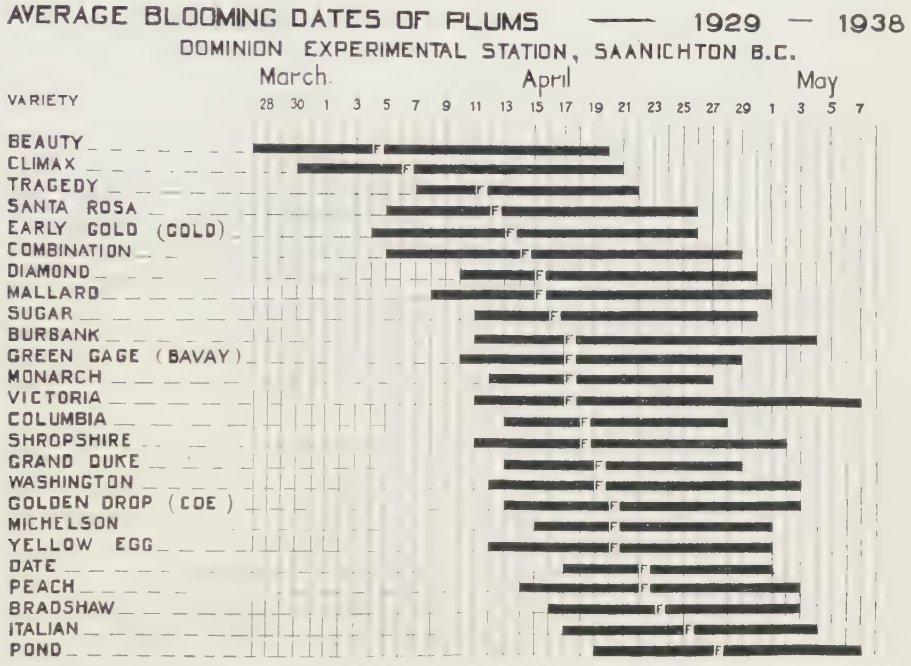

FIGURE I.

MATERIALS AND METHODS

The plum orchard at the Dominion Experimental Station, Saanichton, B.C., contains 25 varieties. Original plantings were made in 1914. Since that time many trees have been replaced so that trees of varying age make up the present plum block. The planting distance is 20 feet × 20 feet.

In the spring of 1932 a study of self-compatibility in commonly grown plum varieties was commenced and extended to include 20 varieties. For many of the varieties found to be self-sterile or nearly so, an effort has been made to determine good commercial plums which might also be used as pollenizers for self-sterile varieties. The number of cross-pollinations carried out has, of necessity, been influenced by the amount of labour and equipment available.

Selfing and controlled-crossing bags were used each season in duplicate. These duplicates were installed on different trees (wherever possible) and all bags were placed on the south side of trees wherever flower buds were available and branches suitable. Flower counts were made at time of installation of bags, set counts about three weeks after the petals fell, and maturity counts when the fruit was fully grown.

A cotton bag, fitted over a wire framework, has been used throughout in these studies. The wire framework is approximately 10 inches in diameter and 16 inches long. When installed, the branch forms an axis passing lengthwise through the centre of the cage where it is held in position by free wire wrapped around the branch at either end of the cage. The branch selected should be reasonably straight, unforked and of sufficient strength to carry the weight of cage and bag. The unbleached cotton bag is pulled over the framework and tied. This method of isolating flowers has been found most satisfactory as the amount of interference of the bag with the flowers is reduced to an almost negligible quantity. Hall (3 and 4) used similar bags and cages in studying the pollination requirements of pear and cherry varieties.

Distribution of pollen to the stigmatic surfaces is carried out by using flower clusters as a brush. This results in thorough distribution with a minimum amount of injury to the delicate flower parts. Self-pollinations and cross-pollinations are made (1) when about 50% of the flowers are open, and (2) just as the latest flowers are opening. This method brings the 2 applications from 3 to 4 days apart and has given satisfactory results. Large paper bags (20 pounds) as pollen-supply bags have been found suitable.

Cross-pollinations have been carried out between many of the more common commercial varieties of plums including Diamond, Golden Drop, Gold, Mallard, Michelson, Peach, Pond, Victoria, Washington and Yellow Egg. Emasculation was not practised in order that labour might be reduced and more pollinations carried out than would otherwise be possible. Injury to the delicate flower parts introduces another factor contributing to error.

Many workers collect and store pollen against the day when it will be needed. This practice has not been followed in these studies. Instead, sufficient bloom is bagged, just before the first flowers open, to give an abundance of pollen for the work required. Varieties as pollenizers can only be useful when supplying viable pollen at the moment it is required. The effectiveness of this means of transferring pollen is shown by comparing yields from controlled-crosses with yields obtained under open-crossing conditions.

Germination tests have not been conducted, but from observations made in the field and from data received from cross-pollinations there is much evidence to show that an abundance of viable pollen is produced by all varieties tested in this experiment.

Disease is a factor frequently contributing to error. Blossoms may be blighted after isolation cages are installed or brown rot of stone fruits may attack the newly set or partly grown fruit. Adjustments have been made in counts wherever it has been noticed that disease interfered, and if the interference has been extensive, data from that unit have been ignored.

Distribution of pollen has been well taken care of by 20 hives of bees in the vicinity of the plum orchard.

RESULTS

A. *Self-compatibility studies.*

Table 1 shows many varieties unable to mature fruit from self-pollinations. These varieties are Burbank, Diamond, Gold, Golden Drop, Grand

TABLE 1.—PERCENTAGE SET OF OPEN-CROSSED AND SELFED FLOWERS IN DIFFERENT VARIETIES OF PLUMS

Variety	Flowers			
	Years	Counted	Set	Matured
	No.	No.	%	%
Bradshaw (P. domestica)				
× Open-crossed	5	893	44.1	29.9
× Self	5	446	43.7	22.1
Burbank (P. triflora)				
× Open-crossed	2	1067	9.8	9.7
× Self	2	790	0.0	0.0
Columbia (P. domestica)				
× Open-crossed	4	1035	8.5	3.5
× Self	4	861	14.0	2.0
Diamond (P. domestica)				
× Open-crossed	7	1766	6.7	5.5
× Self	5	874	0.0	0.0
Gold (P. hortulana × P. triflora)				
× Open-crossed	6	2363	4.3	1.0
× Self	6	1449	1.4	0.0
Golden Drop (P. domestica)				
× Open-crossed	8	2455	13.2	8.3
× Self	5	1040	4.0	0.0
Grand Duke (P. domestica)				
× Open-crossed	3	566	2.1	1.6
× Self	3	328	0.0	0.0
Greengage (P. domestica)				
× Open-crossed	5	798	18.9	12.2
× Self	5	607	35.9	21.0
Italian (P. domestica)				
× Open-crossed	7	2023	15.5	12.1
× Self	7	1188	6.6	5.5
Mallard (P. domestica)				
× Open-crossed	8	1763	24.5	18.1
× Self	6	795	0.1	0.0
Michelson (P. domestica)				
× Open-crossed	7	1577	7.8	6.7
× Self	5	629	0.1	0.0
Monarch (P. domestica)				
× Open-crossed	6	1348	18.3	12.6
× Self	6	831	15.6	12.1
Peach (P. domestica)				
× Open-crossed	8	2506	8.8	4.7
× Self	6	1185	0.0	0.0
Pond (P. domestica)				
× Open-crossed	5	869	7.0	5.8
× Self	5	523	5.5	0.1
Santa Rosa (P. triflora)				
× Open-crossed	2	606	0.3	0.0
× Self	2	358	0.9	0.3

TABLE 1.—PERCENTAGE SET OF OPEN-CROSSED AND SELFED FLOWERS IN DIFFERENT VARIETIES OF PLUMS—*Concluded*

Variety	Flowers			
	Years	Counted	Set	Matured
	No.	No.	%	%
Shropshire Damson (P. insititia)				
× Open-crossed	2	714	17.0	16.2
× Self	2	500	8.0	6.4
Sugar (P. domestica)				
× Open-crossed	5	1097	30.4	19.3
× Self	5	814	31.3	17.2
Victoria (P. domestica)				
× Open-crossed	4	849	26.7	14.0
× Self	4	733	28.4	18.5
Washington (P. domestica)				
× Open-crossed	8	1857	20.8	15.5
× Self	5	560	0.0	0.0
Yellow Egg (P. domestica)				
× Open-crossed	7	1158	21.6	17.7
× Self	6	416	26.6	16.1

Duke, Mallard, Michelson, Peach, Pond and Washington. In a few of these varieties rather low sets have been recorded but the fruit failed to go on to maturity. Self-pollinations in Monarch, Sugar, Bradshaw and Yellow Egg approximated results obtained from open crossing. In Greengage and Victoria considerably more fruit matured from self-pollinations than from open-crossing. More importance is attached to the number of fruit maturing than to the set counts in determining the effectiveness of a pollen. The relationship between the number of fruits set and the number maturing would seem to vary with the variety and the pollen used.

A survey of the 20 plum varieties discussed in this article shows 16 belonging to the European group of *P. domestica*. Of these, 8 are self-incompatible. Five of the remaining varieties gave yields from self-pollinations equal to or greater than yields received from cross-pollinations. A high degree of cross-compatibility exists in most varieties of *P. domestica* and in no case was inter-sterility noted although in one or two instances, such as Mallard pollen or Peach, light yields resulted. Hendrickson (5) reports similar findings in California.

In *P. triflora* (Japanese) Burbank was self-sterile and Santa Rosa nearly so. Yields from self-pollinations for 2 years were almost negligible.

A study of the material upon which Table 1 is based shows 10.1% of open-pollinated flowers matured fruit as compared to 5.1% of self-pollinated flowers. This average set is for the 20 varieties tested. Table 2 presents a summary for all varieties of flowers counted, with average set and average number of flowers developing into matured fruit.

B. *Cross-Compatibility Studies*

Tables 1 and 2 clearly show the superiority of cross-pollinations over self-pollinations when all varieties are considered. Many varieties have

TABLE 2.—SUMMARY OF TABLE 1 FOR TWENTY PLUM VARIETIES

	Flowers		
	Counted	Set	Matured
	No.	%	%
Open-crossed	25551	14.7	10.1
Self	14153	10.9	5.1

been tested as pollinators for popular commercial varieties that are self-incompatible or nearly so. Results obtained are shown in Tables 3 to 11, along with results from open and self-pollinations.

In Table 3, Diamond is shown to be self-sterile over a 5-year period. One variety only, Victoria, has been tested as a pollinator and has shown itself very effective, giving a greatly increased yield over open-pollination.

TABLE 3.—EFFECT OF VICTORIA AS A POLLENIZER FOR DIAMOND

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Diamond:				
× Open-crossed	7	1766	6.7	5.5
× Self	5	874	0.0	0.0
× Victoria	5	1080	38.6	23.8

Golden Drop is shown to be completely self-sterile (Table 4). Pollenizing varieties tested have all shown their value, giving greatly increased yields over open-crossing. Victoria pollen was most effective.

TABLE 4.—EFFECT OF VARIOUS VARIETIES OF PLUMS AS POLLINATORS FOR GOLDEN DROP

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Golden Drop				
× Open-crossed	8	2455	13.2	8.3
× Self	5	1134	4.1	0.0
× Peach	4	846	32.1	22.2
× Pond	4	746	25.7	20.9
× Victoria	5	1010	36.4	29.4

Michelson and Santa Rosa pollens on Gold (Table 5) increased the yield over open-pollinations but these yields were not sufficiently high to be satisfactory. Gold flowers in early season when a limited amount of pollen is available and when adverse weather conditions frequently prevail. Further trials will, we hope, be more conclusive.

Four of the 5 varieties tested as pollenizers for Mallard proved to be effective, giving yields in excess of those obtained under open-crossing

conditions. Michelson was most effective over a 5-year period, while Gold showed no compatibility with Mallard.

TABLE 5.—EFFECT OF DIFFERENT VARIETIES OF PLUMS AS POLLENIZERS FOR GOLD

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Gold				
× Open-crossed	6	2363	4.3	1.0
× Self	6	1449	1.4	0.0
× Michelson	2	816	3.0	2.3
× Santa Rosa	2	766	1.8	1.8

TABLE 6.—EFFECT OF DIFFERENT VARIETIES OF PLUMS AS POLLENIZERS FOR MALLARD

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Mallard				
× Open-crossed	8	1763	24.5	18.1
× Self	6	795	0.1	0.0
× Diamond	4	605	29.7	24.7
× Gold	2	268	0.0	0.0
× Greengage	4	658	22.3	19.4
× Michelson	5	462	34.2	31.8
× Victoria	2	673	25.8	23.7

Self-pollinations were non-effective on Michelson. Open-crossing gave yields below the average for all varieties. Of 3 varieties tested as pollenizers Mallard was most effective giving 15.0% of flowers developing into mature fruit.

TABLE 7.—EFFECT OF VARIOUS PLUM VARIETIES AS POLLENIZERS FOR MICHELSON

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Michelson				
× Open-crossed	7	1577	7.8	6.7
× Self	5	629	0.1	0.0
× Gold	3	286	0.0	0.0
× Mallard	2	353	16.7	15.0
× Peach	5	809	9.1	8.0

Peach is another self-sterile variety (Table 8). Of the 6 varieties tested as pollenizers Michelson was most effective for a 2-year period and 5 of the 6 varieties tested gave yields greater than that which was received from open-crossing.

TABLE 8.—EFFECT OF DIFFERENT VARIETIES OF PLUMS AS POLLENIZERS FOR PEACH

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Peach				
× Open-crossed	8	2506	8.8	4.7
× Self	6	1185	0.0	0.0
× Golden Drop	4	1288	8.3	6.2
× Italian	4	793	13.5	9.2
× Mallard	5	872	2.5	2.5
× Michelson	2	459	26.3	17.2
× Victoria	5	963	16.1	12.8
× Yellow Egg	4	966	16.6	10.9

In Table 9, Italian is shown to be partially self-fruitful. Golden Drop, tested over a period of 3 years, has given yields similar to those obtained from open-crossing.

TABLE 9.—EFFECT OF GOLDEN DROP AS A POLLENIZER FOR ITALIAN

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Italian				
× Open-crossed	7	2023	15.5	12.1
× Self	7	1188	6.6	5.5
× Golden Drop	3	497	14.8	11.6

Washington is wholly self-incompatible (Table 10). Mallard, Greengage, Michelson and Victoria were used as pollenizers with the result that a relatively high degree of compatibility was found to exist between Washington and Victoria.

TABLE 10.—EFFECT OF DIFFERENT VARIETIES OF PLUMS AS POLLENIZERS FOR WASHINGTON

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Washington				
× Open-crossed	8	1857	20.8	15.5
× Self	6	717	0.0	0.0
× Greengage	4	465	12.9	11.4
× Mallard	5	487	9.8	7.8
× Michelson	2	219	15.0	11.4
× Victoria	5	517	31.7	25.1

The Yellow Egg plum is shown in Table 11 to be almost wholly self-compatible. Self-pollinations gave results practically equal to those obtained from cross-pollinations. Victoria pollen more than doubled the yield obtained from open-pollination.

TABLE 11.—EFFECT OF VICTORIA AS A POLLENIZER FOR YELLOW EGG

Variety	Years	Flowers		
		Counted	Set	Matured
		No.	%	%
Yellow Egg				
× Open-crossed	7	1158	21.6	17.7
× Self	6	416	26.6	16.1
× Victoria	4	307	43.3	40.3

SUMMARY

1. Many commonly grown plum varieties are self-incompatible. Of the 20 varieties tested, 10 failed to mature fruit from self-pollinations. These were Burbank, Diamond, Gold, Golden Drop, Grand Duke, Mallard, Michelson, Peach, Pond and Washington.

2. Self-pollinations in Monarch, Sugar, Bradshaw and Yellow Egg gave results similar to those obtained from open-crossing.

3. In Greengage and Victoria considerably more fruit matured from self-pollinations than from open-crossing.

4. Table showing the relative pollenizing value of plum varieties, under test, which have given satisfactory yields when compared with yields obtained under open-crossing conditions:

Female Parent	Table No.	Pollenizing Variety		
		1st	2nd.	3rd
Diamond	3	Victoria		
Golden Drop	4	Victoria	Peach	Pond
Gold	5	Michelson		
Mallard	6	Michelson	Diamond	Victoria
Michelson	7	Mallard	Peach	
Peach	8	Michelson	Victoria	Yellow Egg
Italian	9	Golden Drop		
Washington	10	Victoria		
Yellow Egg	11	Victoria		

5. Victoria and Michelson are effective pollenizers for several varieties and would seem to be valuable general pollenizers.

6. Pollen was produced by all varieties under observation in abundance.

7. Except between earliest and latest varieties to bloom, sufficient overlapping occurs in blooming periods to provide a supply of pollen while the stigmatic surfaces are receptive.

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